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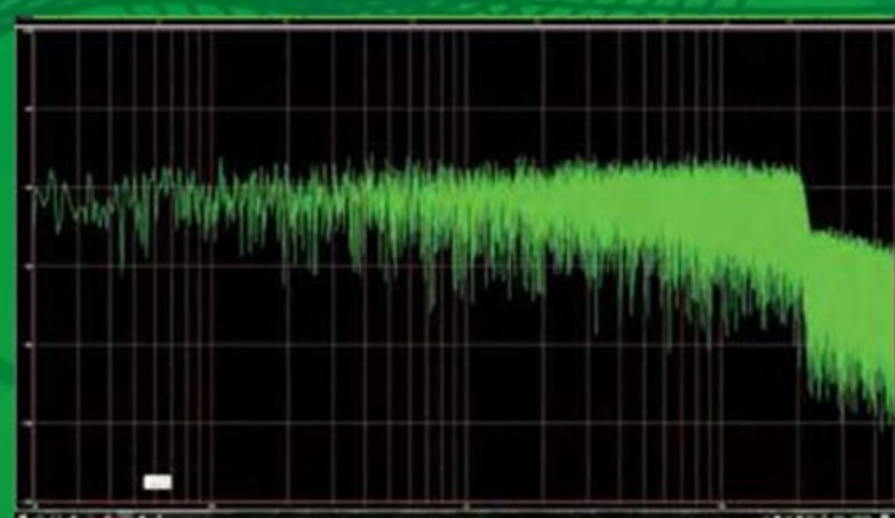


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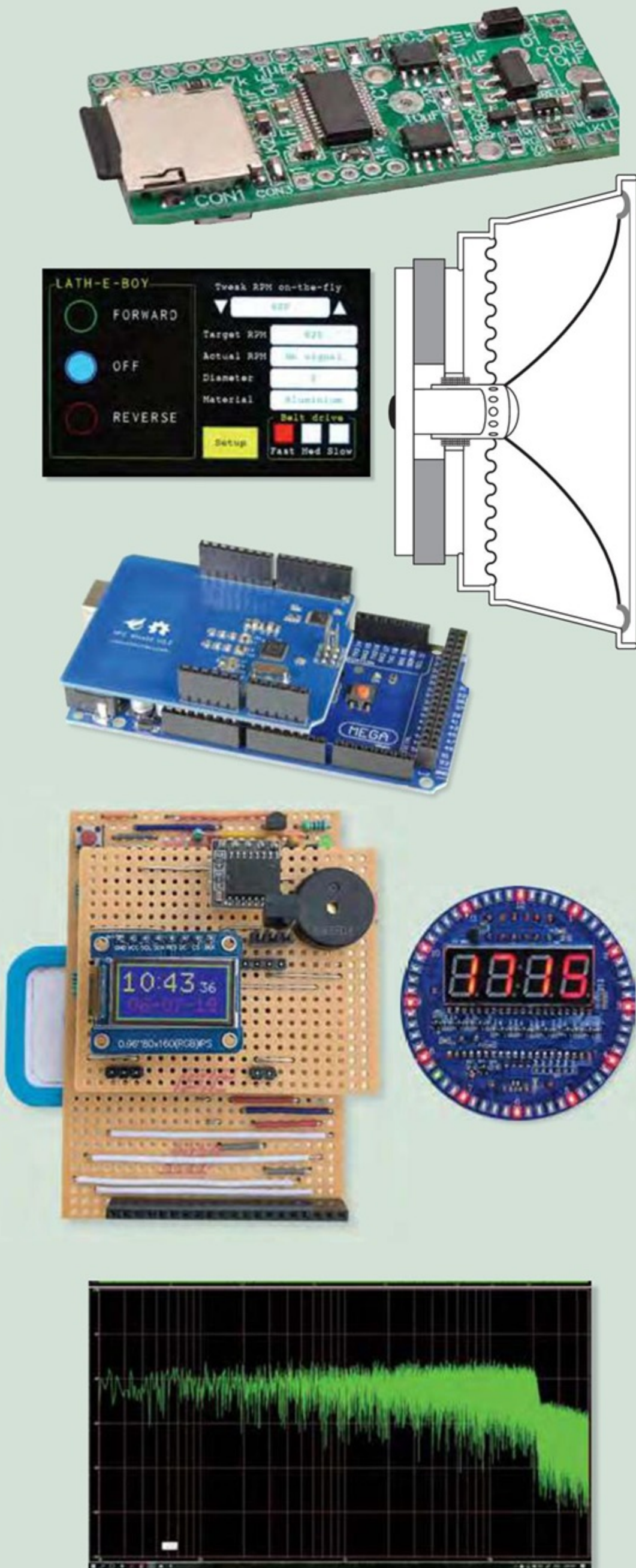
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Questions about articles or projects should be sent to the editor by email: pe@electronpublishing.com

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All reasonable precautions are taken to ensure that the advice and data given to readers is reliable. We cannot, however, guarantee it and we cannot accept legal responsibility for it.

A number of projects and circuits published in *Practical Electronics* employ voltages that can be lethal. You should not build, test, modify or renovate any item of mains-powered equipment unless you fully understand the safety aspects involved and you use an RCD (GFCI) adaptor.

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Inspirational speakers

We don't cover loudspeakers very often in *PE*, certainly much less than amplifiers. Yet they play just as critical a role in audio and are fascinating engineering systems that combine everything from woodwork to advanced filter design – and yes, electronics if you go the active route. Still, if you wait long enough, just like buses, a pair of speaker articles will arrive together!

This month, we take two very different routes to designing and building loudspeakers. We have a remarkably simply electric guitar / PA dipole speaker, which despite its basic construction really delivers the goods. Plus, we have the start of a series from Jake Rothman in his *Audio Out* column that looks at the venerable BBC mini-monitor, the LS3/5A. This won't just be an academic analysis of what makes this speaker so good; we'll be producing designs that enable you to build a pair yourself. This promises to be a really exciting project and I hope you consider making your own LS3/5As. (We'll even make sure the woodwork is rock solid, easy to assemble and inexpensive.)

Practically Speaking

It's over three years since Robert Penfold retired and his popular hands-on column, *Practically Speaking*, came to an end. It was a great mix of advice, tips and tricks that explained in simple language how to actually build circuits and projects. I have wanted to resurrect it for some time, but I couldn't decide which of our many talented writers would be the best fit. Then it struck me... most of them would make a great job of writing the column, so I am going to commission several authors to write the new-look *Practically Speaking*. This month kicks off with *Cool Beans* Max, who declares his love for some decidedly low-tech hardware!

What would you like to see covered in *Practically Speaking*? All construction techniques and technologies are up for grabs – drop me a line and let me know.

Super summer sale!

Here's a short reminder that we're still running our annual summer sale (see opposite). Many PCBs, all back issues and all back issue CD-ROMs are discounted, and don't forget that if you renew your subscription between now and the end of September we're giving away your choice of a six-month back-issue CD-ROM with every 12-month subscription, and three CD-ROMs if you renew for 24 months.

Even if you've renewed recently you won't lose out, your additional subscription will simply start after the current one ends and you're guaranteed to avoid any price rises. In fact, if you've just renewed, but decide to take up this offer you won't see any price rises for the best part of three years. What are you waiting for? Grab a bargain!

Matt Pulzer
Publisher



NEWS

A roundup of the latest news from the world of electronics and technology

Raspberry Pi 4

The Raspberry Pi Foundation has announced the latest iteration of its hugely successful single-card computer – the Raspberry Pi 4.

Starting at \$35, the new Pi is offered as: ‘a comprehensive upgrade, touching almost every element of the platform. For the first time we provide a PC-like level of performance for most users, while retaining the interfacing capabilities and hackability of the classic Raspberry Pi line.’ Highlights of the Raspberry Pi 4 Model B include:

- A 1.5GHz quad-core 64-bit ARM Cortex-A72 CPU (~3× performance)
- 1GB, 2GB, or 4GB of LPDDR4 SDRAM
- Full-throughput Gigabit Ethernet
- Dual-band 802.11ac wireless networking
- Bluetooth 5.0
- Two USB 3.0 and two USB 2.0 ports
- Dual monitor support, at resolutions up to 4K
- VideoCore VI graphics, supporting OpenGL ES 3.x
- 4Kp60 hardware decode of HEVC video
- Complete compatibility with earlier Raspberry Pi products

For the first time there is a choice of memory capacities:

RAM	Price
1GB	£35
2GB	£45
4GB	£55

A Raspberry Pi 4 desktop kit is also available for \$120, and comprises:

- 4GB Raspberry Pi 4
- Official case
- Official PSU
- Official mouse and keyboard
- Pair of HDMI cables
- Copy of updated *Beginner's Guide*
- Pre-installed 16GB microSD card

New features

Pi 4 has moved from USB micro-B to USB-C power connector, supporting an extra 500mA of current, ensuring a full 1.2A for downstream USB devices, even under heavy CPU load.

To accommodate dual display output within the existing board footprint, the type-A (full-size) HDMI connector has been replaced with a pair of type-D (micro) HDMI connectors.

The Gigabit Ethernet magjack has moved to the top right of the board, from the bottom right, greatly simplifying PCB routing. The 4-pin Power-over-Ethernet (PoE) connector remains in the same location, so Raspberry Pi 4 remains compatible with the PoE HAT.

To support Raspberry Pi 4, a radically overhauled operating system is being shipped, based on the forthcoming Debian 10 Buster release. This brings numerous behind-the-scenes technical improvements, along with an extensively modernised user interface, and updated applications including the Chromium 74 web browser.



Power supply

Last, but not least, the Foundation has noted that good, low-cost USB-C power supplies (and USB-C cables) are surprisingly hard to find – something they claim to have noticed when they sent out prototype units to alpha testers. They have worked with Ktec to develop a suitable 5V/3A power supply, which is priced at \$8, and is available in UK (type G), European (type C), North American (type A) and Australian (type I) plug formats.



The all-new Raspberry Pi 4, with up to 4GB of RAM.



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The Fox Report

Barry Fox's technology column



Oil error message



LIQUI MOLY CEO Ernst Prost is infuriated by computer problems – we all know how he feels, but it's rare to go so public.

Journalists grow weary of press releases that gloss over company problems and computer catastrophes. So full marks to German lubricant specialist LIQUI MOLY for what must surely rank as the world's frankest-ever press missive.

'The introduction of new company software in January has turned LIQUI MOLY into a permanent building site,' it reads. 'The system that was supposed to simplify processes and reduce costs for the oil and additive specialist, has had precisely the opposite effect'.

'If we were listed on the stock exchange, I would have to issue a profit warning,' says CEO Ernst Prost, who sent a photo showing how he feels.

'Among other things, the company software manages purchases, controls production, handles shipping and issues invoices...The previous software had been in use for decades and was increasingly reaching its limits. So, after years of preparation, it was replaced.'

'But instead of the anticipated minor teething issues, there were major difficulties that are still ongoing,' says the CEO. 'Customers are becoming frustrated and angry. In my entire professional career, I have not had to apologise so often to customers, as I have had to in the last six months. In addition to the huge cost of having the software installed, every day produces new things to trouble shoot and problems to solve.'

'Earnings for the half-year fell by around 30% to €11m. I never would have thought that in 2019 a change of software could send a whole company skidding off the road.'

'The storm that we are currently going through is a lot stronger than predicted. Big waves are breaking over our ship, some of the crew are getting wet and some of the passengers are a bit nauseous. But our ship is seaworthy and not at risk. And the storm will soon be over.'



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Techno Talk

Mark Nelson

Forget corner cafés – Internet cafés too! That's because the Repair Café is the new 'in' place to be. They are part of a movement that aims to reduce waste, pollution and greenhouse emissions by helping people give their electronic and electrical gizmos a second life. Practical electronicists like you can volunteer to do hands-on mending or contribute by sharing data and solutions for familiar consumer durables.

One of the frustrating factors of modern life is that many gadgets are cheaper to replace than repair. Modern economics may well rely on disposable durables (now there's a contradiction!) and high levels of consumption, but in our heart of hearts we know that the constant replacement of gadgets and burying the evidence of this profligacy in landfill cannot be good for the environment. Regular junking of products that ought to last five years or more is often ascribed to intentional 'planned obsolescence', in which products are designed not to endure but be replaced on a frequent basis to feed economic demand. This all-too-familiar scenario has got to be wrong, and a global movement is growing to put this right.

People power

Big business will not help avert this nonsense unless forced to, so it's down to consumers like us to act. Individuals can kickstart the movement – and they have. In 2009, Dutch journalist Martine Postma ran an experiment in her home town of Amsterdam. She brought together a group of handy friends and ran what she called a *Repair Café* – a free facility where people could bring their broken belongings and motivated volunteers would help to try and fix them.

Following the huge popularity of the events in Amsterdam, Martine set up the Repair Café Foundation (<https://repaircafe.org/en/>) and published guidance to assist volunteers to do the same in

other places. A decade later, there are 1,700 *Repair Cafés* offering their services across 35 countries.

Legal action

The grassroots movement to bring repairing back into our economy is growing and making political demands too, taking on the world's biggest companies through legislation that will force them to make products that are repairable and live longer. According to the Rapid Transition Movement (www.rapidtransition.org), from the EU to the US, new laws are being developed to support the 'right to repair' to radically reduce waste, make things last longer and make them easier to repair. The giant economy of California is now the 18th US state to make such a proposal.

Practical matters

We've already dealt with the who and why, so now let's deal with the what and where – in that order. *Repair Cafés* are free meeting places and they're all about repairing things, communally. At *Repair Cafés* you'll find tools and materials to help you make any repairs you need. On clothing, furniture, electrical goods, bicycles, crockery, appliances, toys and other consumer items. You'll also find expert volunteers, with repair skills in all kinds of fields.

Visitors (clients) bring their broken items from home. Together with the specialists on site, they start making their repairs. It's an ongoing learning process. If you have nothing to repair, you can just enjoy a cup of tea or coffee. Or you can lend a hand with someone else's repair job. You can also get inspired to do some reading – by leafing through books on repairs and DIY. You can visit a *Repair Café* in your own area (<https://repaircafe.org/en/visit/>) or start one yourself (<https://repaircafe.org/en/start/>). The house rules are not onerous (<https://repaircafe.org/en/house-rules/>).

And there's more...

As well as *Repair Cafés* there is also the *Restart Project*. This is a repair café

(with a small 'r' and 'c') that concentrates on mending electronic goods. It started in London in 2013, and since then has helped 11,942 people, by way of 18,978 hours of volunteered time working on 9,648 devices. A survey of participants attending 'restart parties' in 2016 found that close to half of people were 'slightly' or 'not at all' confident undertaking repairs of their goods at home, and that 45% were unable to find a commercial repairer they could trust. Without the help of *Restart* volunteers, many of the goods repaired would have been discarded.

Wishful thinking?

Volunteering has enormous practical power – each month more than 20,000 talented 'fixers' now offer their time and their hands to help over 50,000 people mend their broken belongings, all for free other than the cost of parts used. This is practical support that helps save money, reduces waste and raw material consumption and builds communities. Even better, in 2017 the efforts of all these volunteers saved around 300,000kg of CO₂ emissions that buying replacement gadgets would have cost. There is something immensely satisfying about resurrecting a dead device, especially for someone who may not be able to afford a new one. Why not put your *PE* talents to good use and get involved!

Letters, we get letters

Not really, but we do get emails. Here's one from loyal reader Sam Finklea across the Pond. Commenting on my tirade against scam telephone calls, he says: 'Mark, we on this side of the pond share your frustration with robocallers, but unfortunately your announcement on our behalf of their demise, as Mark Twain said under similar circumstances, "is premature". Regrettably, Congress has not yet acted, nor has the FCC imposed effective rule changes.'

Thanks for your clarification, Sam. Let's hope that the scammers waste the time of sufficient Congresspeople to stimulate some action soon!

Repair culture: the numbers (February 2019)

- A decade on since the first *Repair Café* was held in Amsterdam in 2009, there are 1,700 *Repair Cafés* in 35 countries.
- According to data contributed to *Restart's* 'Fixometer', 54% of all products brought to a Restart Party are repaired on the spot; a further 27% are 'repairable' once a spare part or relevant tool is procured.

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Net Work

Alan Winstanley

This month, we examine the rapid transformation of electricity generation in the UK and the rise of automotive smart systems. Plus, 'Newsbeat' updates on SpaceX, Huawei and Internet radio.

Exactly 20 years ago I was researching a mini-series on electricity generation called *From Pipelines to Pylons for Everyday Practical Electronics*. The UK power generation company National Power, as it was then called, allowed me to clamber all over a relatively new combined cycle gas turbine (CCGT) 650MW power station – Killingholme 'A' – during its maintenance shutdown period. Everything was laid bare, and over several weeks I plotted the story of electricity generation, starting from the natural gas that supplied the power station, through the turbines and 400kV pylons and all the way to the mains outlets found in Britain's homes and factories. The power station had been built in the 1990s in a period dubbed 'the dash for gas', when a newly privatised British energy market erected a whole crop of these 'off-the-shelf' power stations, fuelled by plentiful supplies of North Sea gas.

As things turned out, the power station would change hands several times, but the increasingly unwanted site failed to attract new owners and ultimately it was closed down. In 2017, it was demolished, as seen in a YouTube video at: <https://youtu.be/m4fmyKF03Gc>

A neighbouring 1GW power station (Killingholme 'B') owned by E.ON also closed: in a promo video, the manufacturer Micronics Flowmeters hailed it as a 'great example of a sustainable and efficient energy provider', but today there's nothing left. (See: <https://youtu.be/gEAN5WFZ6eI>).

It was hoped that new CCS (carbon-capture and storage) power plants would replace these power stations, but government funding for the unproven technology was withdrawn. For anyone interested, the writer's original mini-series can be downloaded from: <http://bit.ly/pe-sep19-nw1>

The winds of charge are blowing...

In 1999, I wrote how nuclear, gas and the 'interconnectors' (power cabled into Britain from overseas) formed the core of Britain's power generation landscape at that time, with coal, oil and hydroelectricity topping up the supply at peak periods. 20 years later, the UK has set an ambitious target of cutting net carbon emissions from its energy sources to zero by the year 2050. In May this year, Britain went for two whole weeks without drawing power from its coal-fired power stations, and for two days an astonishing quarter of electricity was solar powered. The UK National Grid (www.national-grid.com) aims to produce more of our electricity from zero-carbon resources than from fossil fuels such as coal and gas. This year, they hope that wind power will account for nearly 19% of the total energy generated, fifteen times more than a decade ago. The country also imports clean hydroelectricity from Norway through the North Sea Link interconnector (see: <http://bit.ly/pe-sep19-nw2>).

Although the author's adopted gas power station is now a distant memory, the local region is seeing massive investment by several major wind turbine factories, including Denmark's Ørsted (<https://orsted.com/en>) and Siemens (<https://sie.ag/2X-QZTsl>) situated in nearby Grimsby and Hull. Their Humber estuary location, coupled with a highly skilled workforce is ideal for building and shipping wind turbines out to sea. Part

of this operation includes the construction of 'Hornsea One', Ørsted's wind farm being built in the North Sea 120km from the seaside resort of Hornsea. Generating 1.2GW of electricity (equal to two Killingholme 'A' power plants), the 400km² wind farm will become the largest offshore wind farm in the world. More details are at <https://hornseaprojectone.co.uk>

Since the Industrial Revolution, Britain's 'evergreen' credentials have been a long time in the making, but there can be no doubt that the country now has some highly ambitious green energy plans, having also developed huge capacity to manufacture and ship wind turbines to meet future demands for this much cleaner form of energy.

Technology in motion

With climate change and green energy still in mind, the move away from petrol and diesel cars to electric vehicles is inexorable. In 2019, Volvo switched to producing 'electrified' hybrid and electric vehicles (EVs) and eventually they will phase out pure ICE (internal combustion engine) cars altogether. Adverts for the latest electric cars from manufacturers including Hyundai, Kia and Renault show the way that industry and society are moving, at the same time mixing together new technology with some old ideas.

Just as the new millennium arrived, on 4 January 2000 the *Daily Telegraph* newspaper printed a headline: *Satellite puts the brakes on speeding drivers*. The paper posited the theory of pairing GPS satellite navigation with some form of 'digital road map' to track a vehicle's location and, if necessary, force it to slow down, perhaps when it broke the prevailing speed limit. It might even force a speed reduction at peak rush hours when passing by schools or other sensitive areas. Fast forward to today and inevitably the idea of technology nagging drivers about their speed has gained traction: the latest cars boast a multitude of electronic driver aids, including road-sign speed limit recognition, which works surprisingly well: a windscreen



Britain's RAC breakdown service offers 'EV Boost' to help jump-start stranded electric vehicles.

camera recognises a traffic speed sign and displays it on the dashboard as a timely reminder. Some in-car sat-nav systems reinforce this by also displaying the speed limits on a map.

Under new EU laws, cars built after May 2022 must employ Intelligent Speed Assistance (ISA) systems like those floated in the *Telegraph* at the turn of the century: legislators propose combining GPS tracking with an in-car GPS-linked speed limit database to determine whether a vehicle is speeding. Hearing of this, the mainstream news media busied itself broadcasting clips showing cars slowing down automatically in response to speed limits, as though the driver had no control over events. In practice, when a speeding infringement is detected the system will merely throttle the engine back to reduce speed without applying the brakes. Some modern cars with 'economy' mode settings work in a similar way, electronically limiting acceleration to save fuel.

New EU cars are also mandated to incorporate eCall, the pan-European '112' emergency service, which uses GPS to summon help automatically in the event of a collision (US readers, think of GM's OnStar.) Cars equipped with eCall will use a GSM connection to provide a voice service and download digital map updates. Traffic sign recognition cameras may also supplement ISA systems. Most of the electronics needed to implement ISA is therefore already available off the shelf and simply needs integrating. Manufacturers are already introducing automatic and manual ISA in their vehicles: a list of current EU cars fitted with ISA can be found at: <http://bit.ly/pe-sep19-nw3>

Looking ahead, to help win over a motoring public faced with the 'threat' of compulsory ISA systems, early examples are expected to have full on-off control and motorists will be able to override the system, for now anyway. It will doubtless only be a matter of time before such choices are taken away from drivers. Future compatibility with the EU's own Galileo satnav system is another consideration; although it still has kinks to iron out since Galileo went down altogether for several days in July.

The entrepreneur behind the SpaceX rocket programme featured last month, Elon Musk, took satellite navigation to a whole new dimension 18 months ago when he launched one of his Tesla cars into space on board a Falcon Heavy. The orbiting car has been 'steered' ever since by a mannequin named 'Starman' to the sound of David Bowie's *Space Oddity* and it holds the record for being the farthest-travelled car in the universe. It is currently travelling at 11,000 mph



A Tesla electric car being driven totally hands-free. Its console has a 17-inch LCD and on-board cameras analyse the surrounding traffic.

and is about 107 million miles away. See www.whereisroadster.com for the latest news. All-electric Tesla cars bristle with electronic technology and are fitted with hardware to enable self-driving in almost all circumstances, they say.

Electric vehicle charging points are starting to appear even in provincial out-of-town retail parks, but when things go wrong can early EV adopters suffering from 'range anxiety' rely on a traditional breakdown recovery service to help? In April, the RAC (Royal Automobile Club) breakdown service launched EV Boost, which enables its service trucks to give stranded EVs a quick charge.

Newsbeat

The US Department-of-Defence-controlled SpaceX mission STP-2 (Space Test Program-2), launched on 25 June, was a Falcon Heavy's first night-time launch. Its 'ride sharing' mission deployed payloads from several sources, including 24 experimental USAF military satellites and a private load comprising the cremated remains of 152 people. STP-2 was the first mission to use 'recycled' side boosters recovered from previous missions, but SpaceX has yet to recover a Falcon Heavy centre core rocket successfully. Meanwhile, SpaceX has lost contact with three of the 60 Starlink satellites launched in May (see last month's column). They are expected to burn up in re-entry sometime in the future, hopefully without generating snowballing clouds of space junk that risk damaging other orbiting satellites – a scenario similar to one envisioned in the disaster movie *Gravity*.

US chip maker Micron has been licensed to re-commence exports of memory chips to Huawei, the embattled Chinese telecoms giant that was prohibited from trading with the US in May (see *Net Work*, August 2019) for reasons of national security. In mid-August, owners

of current Huawei smartphones hope to learn whether or not Google can continue releasing apps, patches and updates for Huawei's current Android phones. They have enjoyed a temporary reprieve from America's technology export ban and indeed the author's Huawei phone suddenly updated itself overnight from Oreo (8.0) to Pie (9.0), possibly a sign of Huawei rushing out OS updates before the shutters come down.

The UK's Department for Digital, Culture, Media and Sport (DCMS) is working with Britain's National Cyber Security centre and others to consult on regulatory proposals regarding consumer Internet of Things (IoT) security, with a view to shifting onto manufacturers the responsibility for securing IoT devices and away from consumers. Under the proposals, certain security requirements would become mandatory.

Car dashcam maker Nextbase has introduced a trio of Alexa-friendly models. Claiming to include the world's first 1440p dashcam with Alexa, the Nextbase 322GW, 422GW and 522GW have Bluetooth and Emergency SOS and Alexa-powered navigation coupled to your smartphone. Rear-window cameras are optional extras and an Alexa skill is promised that offers voice control of the dashcam. More details at: www.nextbase.com

If you enjoy listening to streaming radio, try www.radio.garden from the Netherlands. It offers a global view of Internet-based radio stations. After populating the globe with 'seeds' (radio stations), simply drag it around and click on a location to tune in. You can add to favourites, visit a station's website and mobile apps are available as well. That's all for now – see you next month for more *Net Work*!

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LATH-E-BOY

This design combines two very popular projects, the Induction Motor Speed Controller and Micromite Plus Explore 100 with 5-inch Touchscreen, then adds some other circuitry, to provide an easy way to control a lathe.

It automatically adjusts its speed to suit the material which is being turned, provides a constant display of the lathe's status and allows its speed and direction to be selected.

Intelligent Touchscreen Lathe Speed Controller

Design by Peter Bennett

–

Words by Nicholas Vinen

Most lathes, apart from small wood-turning machines, are powered by an induction motor. The problem with using an induction motor is that until quite recently, the most common ways to control lathe chuck speeds involved belts and stepped pulleys or a gear box.

While they are still useful, it is now possible to control chuck speed and direction using our *1.5kW Induction Motor Speed Controller (IMSC)*, which was originally published in the January and February 2019 issues of *PE*.

In addition to providing speed/direction functions, why not provide extra features such as a speed read-out, touch-screen control interface and so on? That's all doable by building an *Explore 100* with the 5-inch touchscreen and then programming it to control the *IMSC*.

You can see from the screen grabs in this article that the *Lathe Controller* interface is quite simple to use and saves you quite a bit of time and effort since all you need to do is specify the material type and diameter and it will automatically select a suitable motor RPM. You can then adjust this further if necessary.

Once you have selected the material type and/or spindle speed, you can then control the motor direction and

fine-tune the speed, while monitoring the actual RPM.

This article gives all the details on adding the extra circuitry required for the *IMSC / Explore 100*, how to hook them up together, and to the lathe, and how to achieve control.

Circuit description

The circuit for this project is shown in Fig.1, overleaf. It is broken up into several blocks, to reflect the physical layout of the system.

The large block at centre right represents the *Micromite Plus Explore 100* unit, with LCD touchscreen. This is housed in a large Jiffy box, along with a few passive components, an optocoupler and four transistors.

These components interface the *Explore 100* to the rest of the circuitry required to control the induction motor.

Those connections are made via two Cat5 cables, which are plugged into 8-pin RJ-45 sockets CON2 and CON3 (note that CON3 only uses six of the eight available wires). Pins 1-2, 3-4, 5-6 and 7-8 are connected to the twisted pairs within the cable (but note that not all Cat5/6 cables are wired like this).

The connections made over Cat5 use current loops and, in the case of the motor speed control signal, 4kHz pulse-

width modulation (PWM). It has been designed this way to allow for relatively long cable runs (of up to 50m). In most cases though, those cables will be a few metres at most.

With CON2, all eight connections between the two main modules (the *IMSC Interface* and the *Explore 100*) are optoisolated so that ground loops are not an issue, despite the possibility of a large distance between the units. This also prevents ground shifts due to the long wiring affecting the accuracy of the control signals.

CON3 connects the *Explore 100* control box to the relay box, which is wired between the outputs of the *IMSC* (shown at left) and the induction motor itself (at bottom right). The relay box switches the two windings of the motor to control start-up and direction of rotation.

The three high-current mains relays are driven by NPN transistors Q1-Q3 within the control box, via the 6-wire cable, and each relay has a coil back-EMF quenching diode.

When RLY2 switches on, it energises the motor start winding. When RLY1 is switched on, it reverses the polarity of this winding, so the motor will start spinning in the opposite direction. As its name suggests, the start winding is

only energised when the motor is first started, hence the relay. After that, the start winding is disconnected so it doesn't burn out. The motor keeps spinning in the direction that it started.

RLY3 is used to energise the Run winding. You may wonder why this is necessary since the *IMSC* can be switched on and off. When the *IMSC* is switched off, it will slowly spin the motor down at the programmed ramp rate. By disconnecting the run winding from the *IMSC*, the lathe motor will spin down more rapidly and naturally, improving safety.

Three LEDs are also fitted into the box housing the *Explore 100*, labelled Reverse (yellow), Start (red) and Run (green). These are effectively wired in parallel with the three relay coils (via CON4), with 560Ω current-limiting resistors in series with each LED. These provide feedback on what the motor is doing.

Speed controller interface

Now turning our attention back to the control circuitry around the *Explore 100* and the second Cat5 cable, this is wired to a small box attached to the side of the *IMSC* which provides an isolated interface to it. A small, separate circuit board labelled 'output frequency sense' is fitted inside the *IMSC* enclosure. Let's take a look at this first.

This is connected across the U and W motor outputs which power the main 'run' winding. The differential voltage between these outputs passes through an RC low-pass filter comprising two 5.1kΩ 1W (mains-rated) resistors and a 220nF X2 mains capacitor. This has a -3dB point of around 71Hz so it filters out the IGBT switching edges.

The resulting sinewave signal is then applied to the infrared LED within a PS2501 Darlington output optoisolator. D4, a 1N4007 diode connected in inverse parallel with this LED prevents it going into reverse breakdown for one half of the output

phase. This means the optocoupler output is switched on to produce one pulse for each AC cycle fed to the motor.

The two extra 5.1kΩ resistors limit the LED current to ~17mA, well within the 80mA rating of the device: $350\text{VDC}_{\text{peak}} \div (4 \times 5.1\text{k}\Omega)$.

The output pulses from the frequency sense circuit are fed right through the *IMSC Interface* box and back to the *Explore 100* unit via pins 1 and 2 of the Cat5 cable. One end of this signal is terminated to the *Explore 100*'s local ground, while the other has a 1.2kΩ pull-up resistor to the 3.3V rail, giving a 3.3V square-wave signal.

This square wave is filtered using a 120kΩ/1μF low-pass filter, before being fed to pin 11 on the *Explore 100* I/O header ('read RPM'). The PIC32 (Micromite Plus) in the *Explore 100* can then count the number of pulses on this pin each second to determine the spindle speed. This RC filter has a time constant of 120ms, which may seem quite long with respect to the 50Hz waveform when the motor is running at full nominal speed, with a 50Hz output. However, the filter has to cope with a pulse rate from 50Hz all the way down to about 5Hz, so the 120ms time constant seems to be a reasonable compromise.

As well as measuring motor speed, the Micromite also needs to be able to control the speed. This is done using the PWM output on pin 22 of the I/O header (CON1), which drives the base of NPN transistor Q4 via a 1kΩ current-limiting resistor. When Q4 is on, it pulls current through the upper LED in the HCPL2531 dual high-speed optocoupler within the *IMSC Interface* module (OPTO2).

Because the emitters of the two output transmitters are joined together, we're only using half of this device. The collector of the output transistor at pin 7 is connected to a 3.3V rail output from the *IMSC*, while the emitter at pin 5 has a 1kΩ pull-down to the analogue



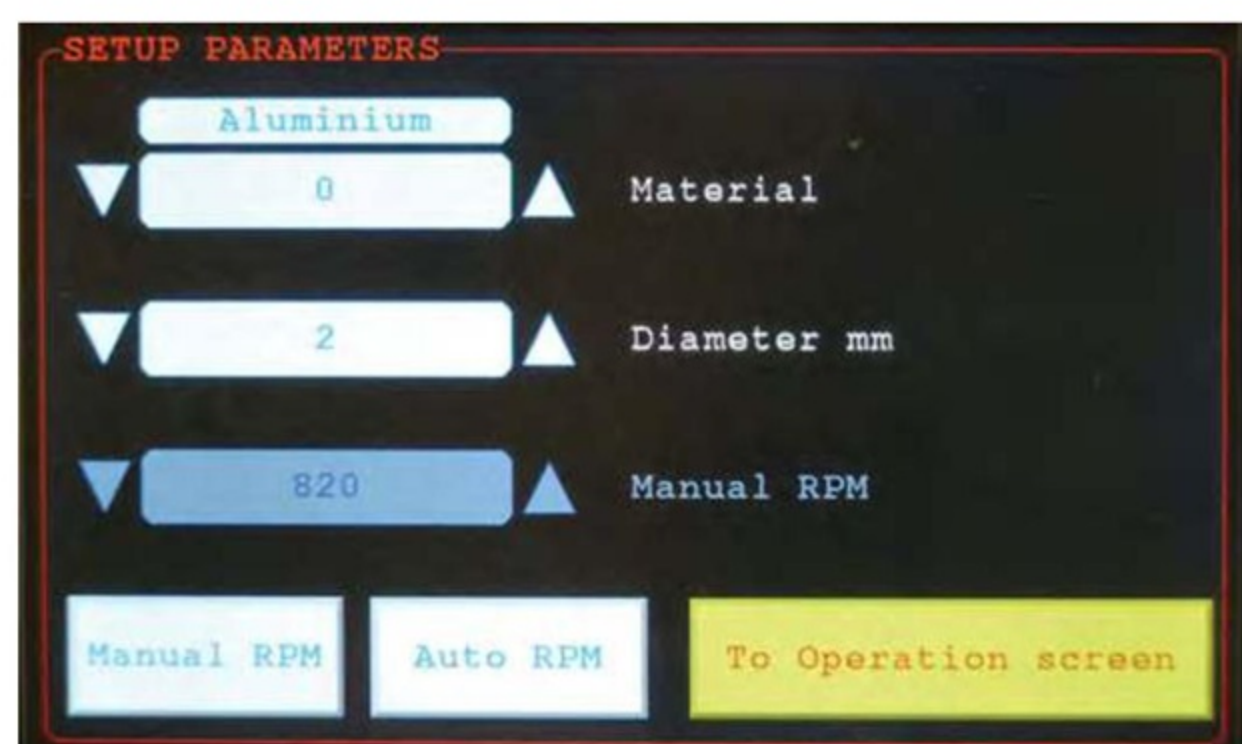
The *IMSC*, interface circuitry, relay box and plugpacks were mounted on the rear of the lathe stand, with the touchscreen controller box up on top.

ground of the *IMSC*, resulting in a 3.3V square wave at pin 5 of OPTO2.

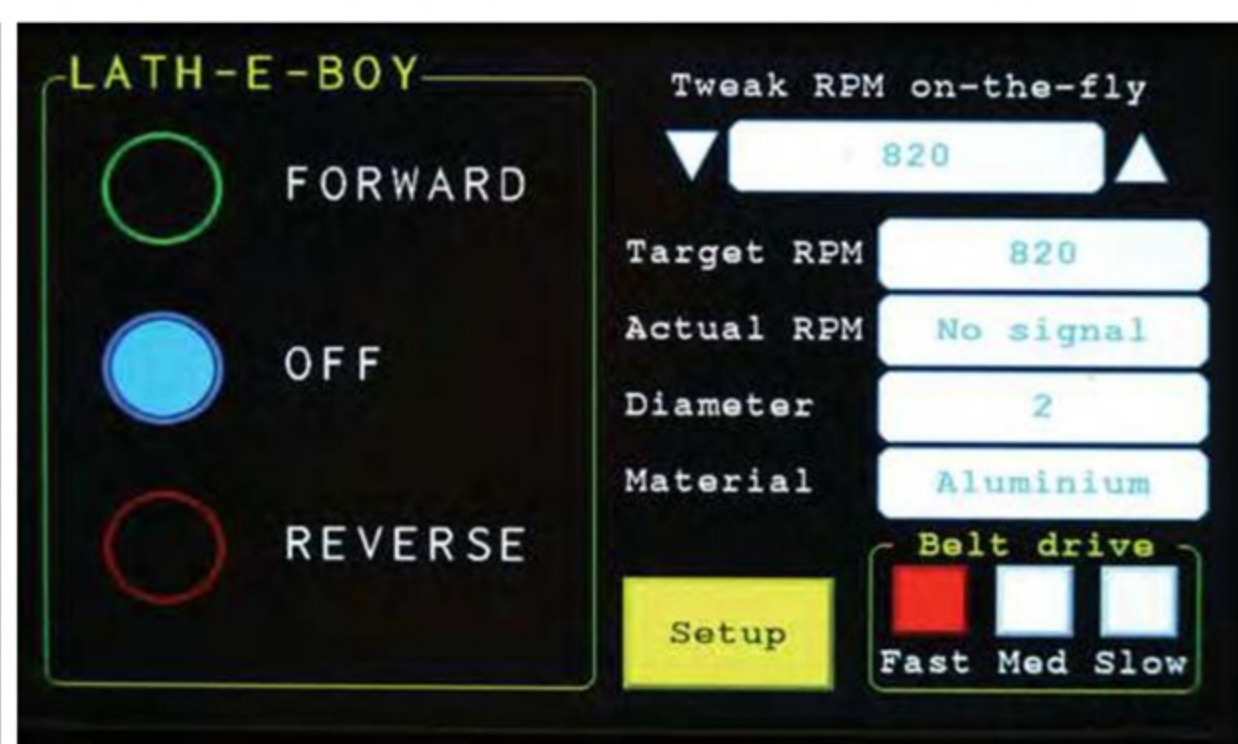
This passes through an RC low-pass filter of 4.7kΩ and 10μF, having a -3dB point of 3.4Hz. This smooths the PWM waveform to produce a variable voltage that depends on the PWM duty cycle. The variable voltage is then fed to the control input (Vin) of the *IMSC*. The 3.3V and GND rails for this part of the circuit are connected only to CON4 on the *IMSC* so that digital noise on other pins does not unduly affect the analogue control signal.

There is a second, Darlington output optocoupler within the *IMSC Interface* (OPTO3) which drives the RUN input at CON5 of the *IMSC*, enabling or disabling the motor output. A 1kΩ pull-up resistor to 3.3V sets the default state to have the motor switched off.

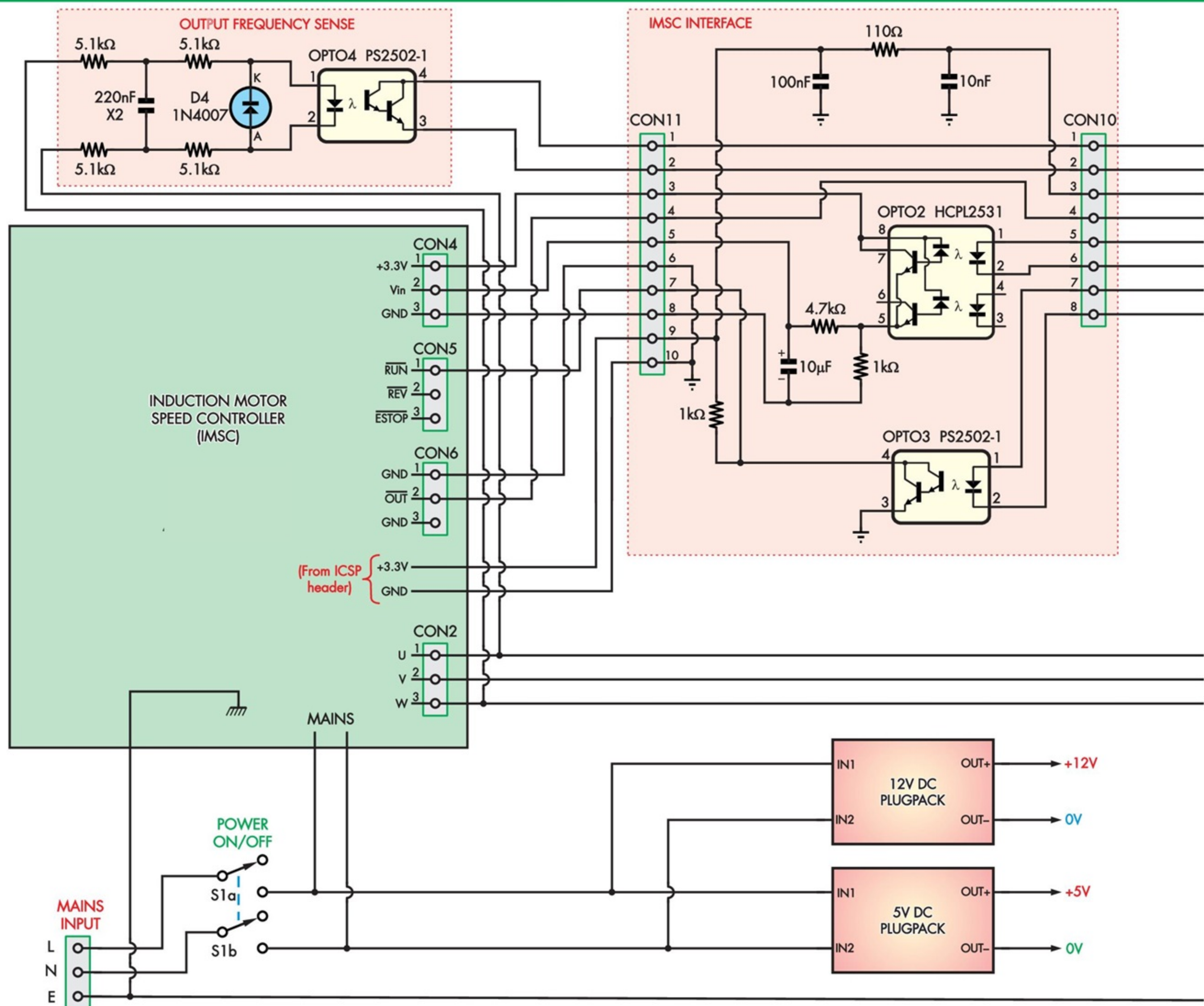
It only switches on when pin 7 on the *Explore 100* I/O header goes high, allowing current to flow through the emitter LED within OPTO3. The LED



Screen1: the setup screen appears when the *Lathe Controller* is first powered on and allows you to set either the material type and diameter, or the chuck RPM.



Screen2: once setup is complete, it switches to this screen where you can start, stop and reverse the motor, monitor chuck speed and tweak it if necessary.



Lath-E-Boy Induction Motor Controller

Fig.1: circuit diagram of the *Lathe Controller*, with the *IMSC* (*Induction Motor Speed Controller*, at left) and *Explore 100* (centre right) circuits shown as ‘black boxes’. See the relevant articles (referred to in text) for internal details. The additional circuitry ties these two modules together as well as providing motor speed feedback, safe motor starting and reversing, feedback-based speed control and status indication.

current is set by a 470Ω resistor between this LED cathode and ground. When pin 7 goes high, OPTO3 switches on, pulling RUN low.

The OUT terminal on CON6 of the IMSC is pulled low by the speed controller when the motor is up to speed. This is fed through the IMSC Interface to arrive at pin 2 of OPTO1, the cathode of its internal emitter LED. The LED anode is connected to the 3.3V supply rail of the IMSC via a pi filter consisting of a 100nF capacitor, a 10nF capacitor and a 110Ω resistor, which also acts as a current limiter.

Thus, when the motor is up to speed and OUT is low, 30mA will flow through this circuit, switching on OPTO1 and pulling its output pin 4 low. This is

normally held high by a 270Ω resistor and this signal is fed to pin 13 of the *Explore 100* I/O (‘Up To Speed’) so that it can be sensed by the Micromite.

Remaining circuitry

Earlier, we described how RLY1-RLY3 are used to start the motor spinning in either direction and then to allow it to continue to run. The coils of the three relays are driven by NPN transistors Q1-Q3, which are in turn controlled from I/O pins 21, 23 and 25 on the *Explore 100*. Each has a $1\text{k}\Omega$ base current limiting resistor and a back-EMF quenching diode connected across the relay coil.

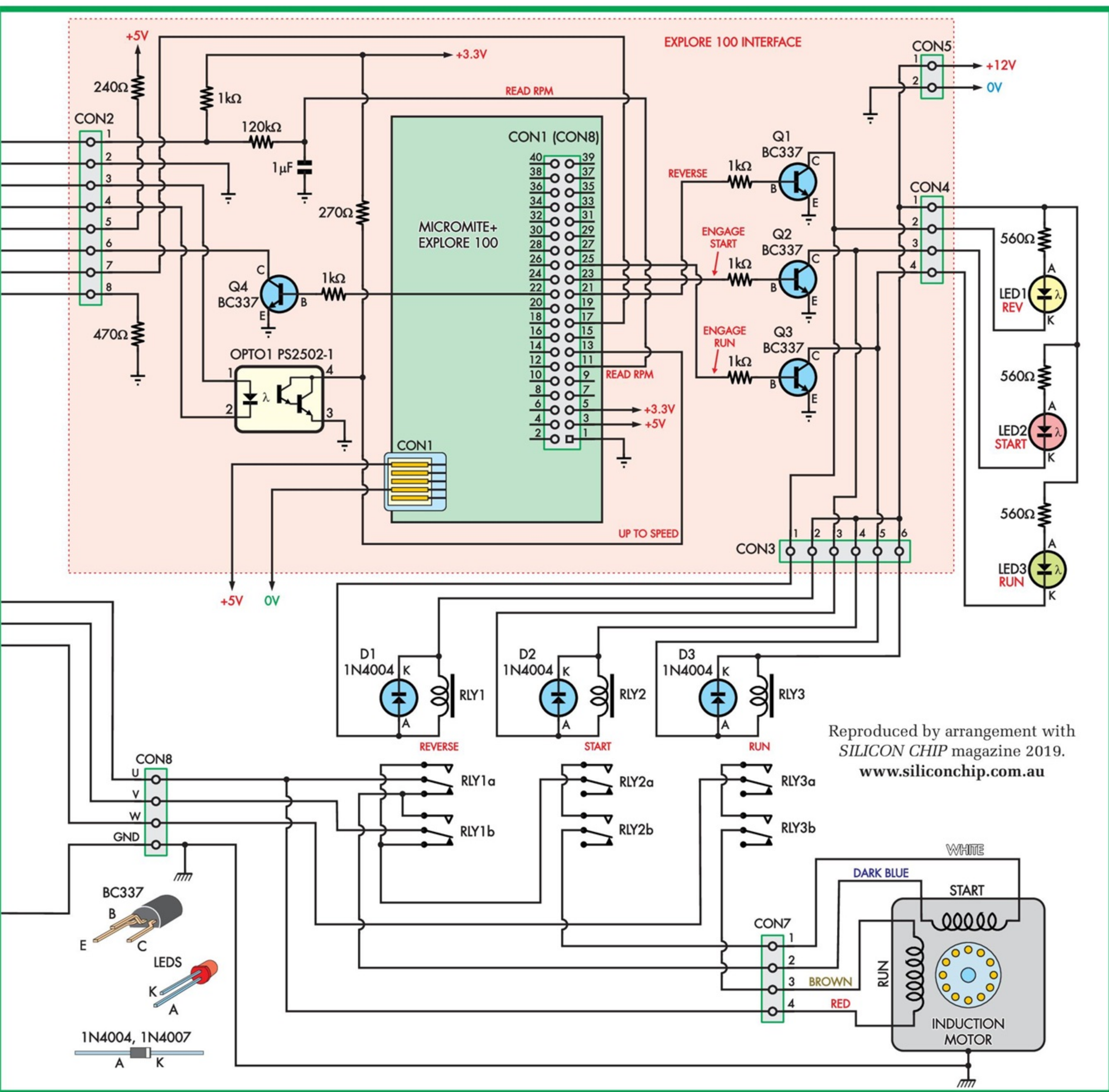
Indicator LEDs1-3 are connected in parallel with the relay coils, each with their own 560Ω current-limiting resistor.

So these LEDs light up to indicate whether the motor start or run winding is energised, and to show which direction the motor is running.

The rest of the circuitry comprises the mains power supply and motor wiring. The 230VAC input plug earth connects to the earth terminals on the IMSC and the motor housing. Live and neutral pass through a double-pole power switch and then onto the input terminals of the IMSC and two plugpacks. The 12V plugpack powers the relays, while the 5V plugpack powers the *Explore 100*.

The rest of the circuitry draws power either from the regulated supply rails within the *Explore 100* or the IMSC.

The three IMSC outputs are wired up to the terminals of relays RLY1-RLY3



and in some cases, directly to the motor terminals.

See the panel elsewhere in this article describing how the motor connections are made. As mentioned earlier, two of the three motor drive outputs (U and W) are also connected to the Output Frequency Sense circuitry.

Software operation

The main goal of this project was to have a supervisory control for the lathe, into which could be entered the material type and diameter to be turned. The software would then set the required speed and would control the lathe to maintain that speed, making the turning process much simpler. The *Explore 100* with 5-inch touchscreen provides the ideal platform.

The set-up screen is shown in Screen1. It provides auto and manual RPM control modes. In auto mode, the user selects material and diameter and the controller does the rest. If manual mode is selected, the user sets the speed regardless of material and diameter. Once the selection has been made, the operation page is displayed, as shown in Screen2.

FORWARD, REVERSE and OFF are self-explanatory. The spinbox 'Tweak RPM on-the-fly' allows the user to switch to manual mode and adjust the motor speed. Target RPM is the speed we want, while Actual RPM is the inferred motor speed, based on the frequency measured at the motor controller output.

This is an excellent proxy for the spindle RPM, as verified with a temporary Hall Effect pickup on the tool post and a magnet on the chuck. The material and diameter selections are repeated on the Operation page.

The three square 'radio' buttons in the lower right corner tell the software which of the three motor belt pulley positions is in use, as this affects the maximum and minimum RPM values. The lower speed pulleys are used only if additional torque is required at low speed. (A 'radio button' is like a checkbox,—except only one in a group can be selected at any given time.)

To ensure the software is responsive, almost all events are handled in interrupt routines, including the touchscreen

interface, which uses the TOUCH (REF) function. The motor speed is sensed by measuring the intervals between an interrupt triggered by the level change on the READ RPM input.

Motor speed control is achieved using a simple proportional feedback strategy. A closed loop continually measures the error and reduces it. Effective gain of this loop is controlled by selecting the time between corrections and the proportion of error applied to each correction.

These numbers are determined by experiment and are quite flexible. Settling time and stability are completely adequate for the purpose. Since the source code is available, the software can be modified by those who would like to adapt it for their own projects.

The only niggle is the loading time of the title or 'splash' screen. This takes nearly 12 seconds to load from the micro SD card.

Perhaps it should be called the 'drip screen'! This is due to the way that MMBasic loads data off the SD card.

Construction

You will need to build and test the *IMSC* and *Explore 100* modules separately before you can build the extra circuitry which ties them together.

If you're building the *IMSC* from a kit, it should come with assembly instructions. Otherwise, refer to our articles in the January and February 2019 issues of *PE*.

For the *Explore 100*, assembly instructions are in the September and October 2017 issue; the only tricky aspects are soldering the few SMDs.

After that, it's pretty much just a matter of soldering the components in place where indicated on the PCB silkscreen.

The prototype *Speed Controller* interface was built into a small Jiffy box which was mounted to the outside of the *IMSC*, while the *Explore 100* interface plugged directly into the *Explore 100*. As you can see from the photo, the 'output frequency sense' section of the circuit was mounted inside the *IMSC* box itself.

The *Explore 100* Interface, *IMSC* Interface and Output Frequency Sense sections of circuitry were built on solder-type prototyping boards using point-to-point wiring, so there are no PCBs or overlay diagrams. The relays were mounted in a separate box with an earthed aluminium backplate, as shown in the photo opposite.

Since each section of the circuit is relatively simple, after soldering the required components to a piece of protoboard, you should be able to use the circuit diagram as a guide to wiring it up. You can use wire-wrap wire (Kynar), bell wire or light-duty hookup wire to make the connections between component pins.

The *Explore 100* and its associated interface components, shown in the shaded box in Fig.1, were housed in a single large jiffy box. You will need to make a rectangular cut-out in the lid for the *Explore 100's* LCD, plus three

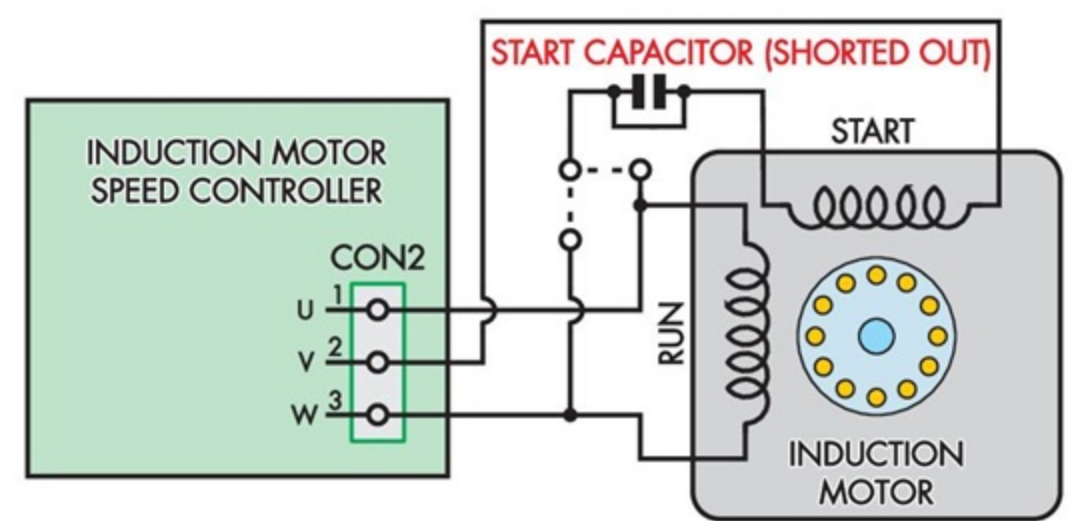


Fig.2: here's how the designer's lathe motor was wired up to the *Speed Controller*, ignoring the relays which control start-up and reversing, for the moment. The start capacitor is shorted out since it's no longer required. Note the two possible ways to wire up the one end of the start winding.

holes for the status indicator LEDs and some holes for wires/sockets for the DC power input and RJ-45 (or DB9, as in the prototype) interface sockets.

Loading and using the software

If you've built the *Explore 100* kit it should come with a pre-programmed microcontroller, but you still need to set up the LCD panel and then load the *Lathe Controller* BASIC code into the *Explore 100*.

You should do this with the *IMSC* and related circuitry powered down – however, the circuit has been designed so that nothing bad should happen if the unit is powered up without any code running on the *Explore 100*.

In other words, the default state of each output is set up to be safe and not drive anything, including the motor.

Instructions for setting up the LCD panel and touchscreen were given in the September and October 2017 issue; however, if you don't have that handy, you can simply enter the following commands over the serial or USB console:

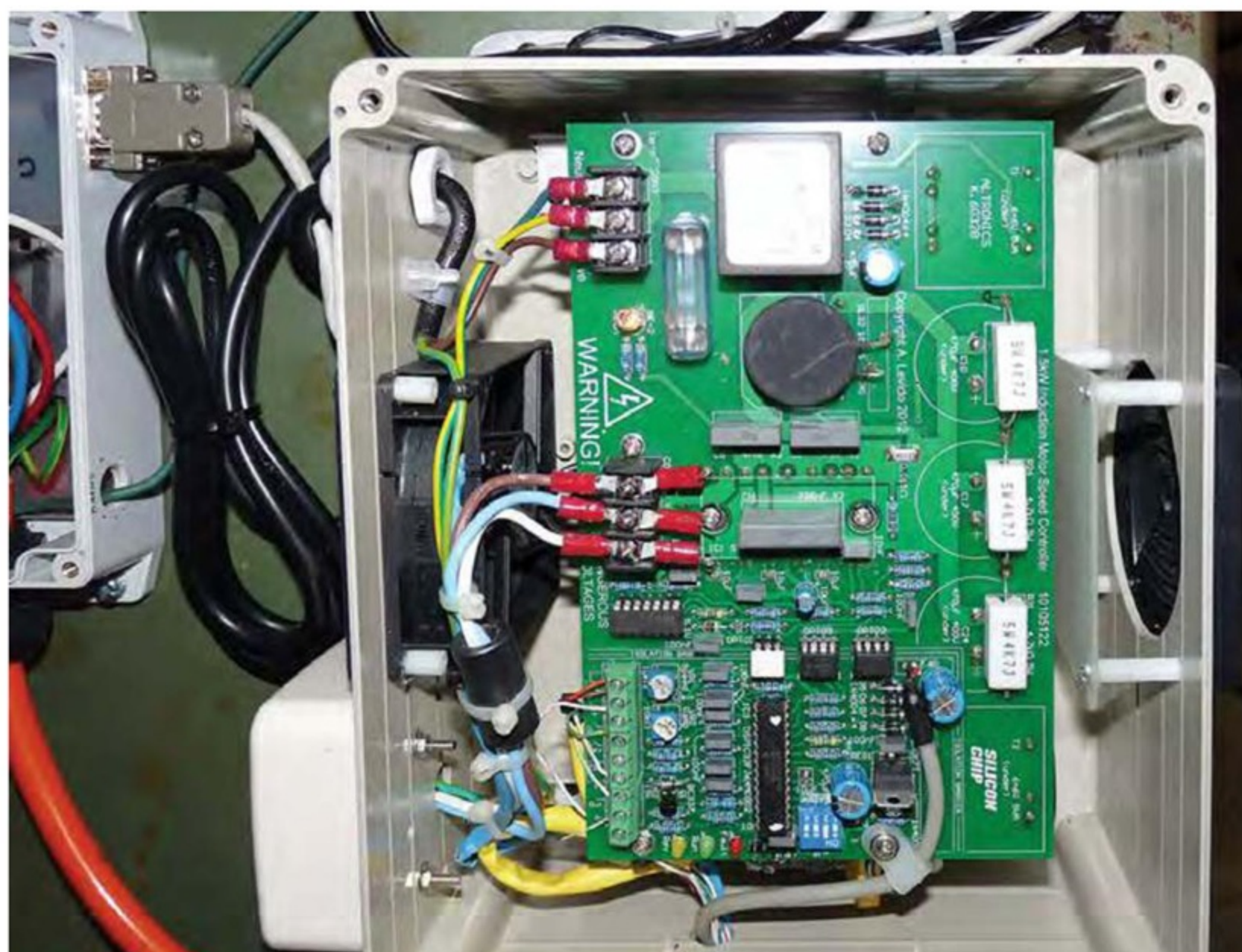
```
OPTION LCDPANEL SSD1963_5, LANDSCAPE, 48
OPTION TOUCH 1, 40, 39
GUI CALIBRATE
```

After typing the final command and pressing enter, you will be presented with a cross-hair target in the corner of the LCD screen.

Press on its centre with a stylus-type object (eg, a toothpick) and then repeat for the targets which appear in the other three corners. With any luck, you will get a message on the console which reads 'Done. No errors' and that indicates that the touchscreen has been set up correctly.

You can then download the *Lathe Controller* BASIC code from the *PE* website and upload it using MMEdit or similar software (MMEdit is a free download for Windows or Linux; see www.c-com.com.au/MMEdit.htm).

Once the code has been uploaded, MMChat should automatically launch

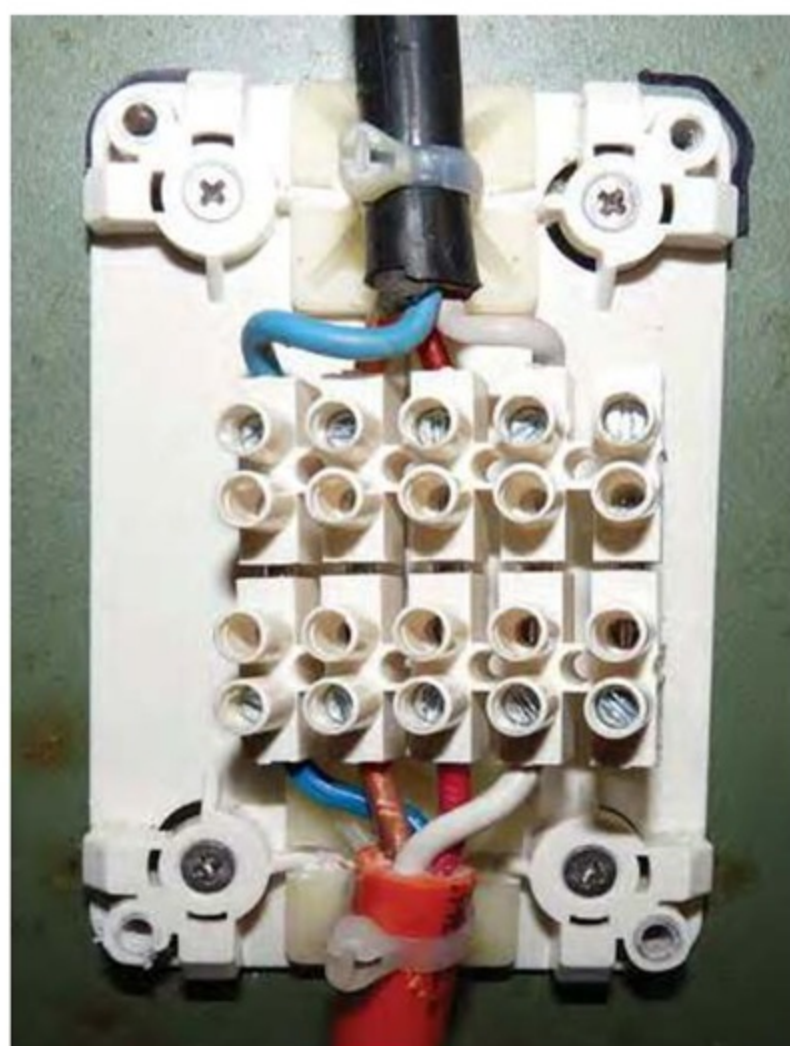


This shows the wiring between the *IMSC* and interface box. The speed feedback board is just visible below the main PCB. Note the improved ventilation.



(Left) The pre-existing direction control switch box, which was wired to both motor windings.

(Below) This junction box connects the Controller outputs to the motor.



and you can then issue the 'OPTION AUTORUN ON' command, followed by 'RUN' and the graphical user interface (GUI) should appear on the LCD screen.

You can verify that this appears to be working before disconnecting your PC and you are then ready to power the whole rig up and test it out properly.

Using a 3-phase motor

While this project was designed to be used with a lathe driven by a single-phase induction motor, the IMSC is capable of driving 3-phase delta-wound motors.

Since a 3-phase motor lacks a start winding, start capacitor and centrifugal switch, you don't need RLY1 or RLY2 and their associated wiring. RLY3 will need to be a four-pole type to allow it to switch all three phases.

However, the design as presented here does not drive the REV terminal on the IMSC so it has no way of commanding motor reversal for a 3-phase motor.

Therefore, you would need to run a connection between the collector of Q1 and the REV terminal on the IMSC so that the Explore 100 can reverse the motor direction. The software should not need any modifications.

Parts list – Lath-e-Boy Lathe Controller

- 1 Induction Motor Speed Controller kit [Altronics Cat K6032]
- 1 Micromite Plus Explore 100 kit from micromite.org
- 1 5-inch diagonal colour LCD to suit Explore 100
[eg, AliExpress.com item 32665326615 or 32659478023]
- 3 10A 250VAC DPDT relays, 12V DC coil (RLY1-RLY3; [Jaycar SY4065])
- 3 DPDT relay cradles (optional, for RLY1-RLY3; [Jaycar SY4064])
- 2 10A mains cables, cut in half (for mains input and to connect plugpacks)
- 1 12V DC 500mA regulated plugpack
- 1 5V DC 1A regulated plugpack
- 1 10A 250VAC DPDT toggle switch (S1)
- 1 10-way connector with matching plug and cable (to connect IMSC Interface to Speed Controller)
- 4 RJ-45 modular connectors
- 2 Cat5(e)/Cat6 cables with twisted pairs 1–2, 3–4, 5–6, 7–8
- 1 large solder type protoboard (cut up as required)
- 1 large jiffy box (for Explore 100 and associated components)
- 1 medium-sized jiffy box (for IMSC Interface)
- 1 diecast aluminium box (to house RLY1-RLY3; must be earthed)
- various lengths and colours mains-rated and light-duty hookup wire

Semiconductors

- 3 PS2502-1 Darlington optocouplers (OPT01, OPT03, OPT04)
- 1 HCPL2531 dual high-speed optocoupler (OPT02)
- 4 BC337 NPN transistors (Q1-Q4)
- 1 yellow 5mm LED (LED1) 1 red 5mm LED (LED2) 1 green 5mm LED (LED3)
- 3 1N4004 1A 400V diodes (D1-D3) 1 1N4007 1A 1000V diode (D4)

Capacitors

- 1 10 μ F 10V electrolytic
- 1 100nF MKT or ceramic
- 1 220nF X2 MKP
- 1 1 μ F multi-layer ceramic
- 1 10nF MKT or ceramic

Resistors (all 0.25W 1% unless otherwise stated)

- 1 120k Ω 4 5.1k Ω (1W 5%) 1 4.7k Ω 7 1k Ω 3 560 Ω 1 470 Ω 1 270 Ω
- 1 240 Ω 1 110 Ω

It's best do this initially with nothing in the lathe so you can verify it's working correctly without risking any damage.

The operation of the software was explained earlier, although it's pretty much self-explanatory anyway.



The relay box, which connects the IMSC to the motor, has an earthed aluminium backplate. If using a 3-phase motor, only two relays are required.

Modifying the motor to allow the speed controller to be connected

It is worth reading the January and February 2019 articles on the Induction Motor Speed Controller to get a background on induction motors and a description of the Controller. While its main purpose was to vary the speed of pool pumps, it was also suitable for the control of machine tools, such as lathes.

Most basic lathes vary the speed of the chuck by changing belts, an inconvenient and inefficient method of approximating the desired speed. As a result, it is likely that many hobbyist lathes remain on the one speed for most of their lives, a far from optimum situation for quality and speed of operation. Variable-speed control is an attractive modification.

Any reasonably sized lathe will use a capacitor-start motor. This has a high starting torque to overcome the load presented by the belts, pulleys, close-fit bearings and back gears, with a centrifugal switch to take the start winding out of circuit as the motor comes up to speed. Unfortunately, the Induction Motor Speed Controller is specified as being unsuitable to drive such a motor. But is it?

The main reason given for the unsuitability is that at a low selected speed, the centrifugal switch will cut back in, and the current drawn by the start winding may burn the winding out. Almost as an afterthought, a sidebar advises that 'there is also a risk that the over-current protection in the Speed Controller will simply prevent normal operation'. Amen to that!

The subject of this project is a 1970s-era Taiwanese lathe with a 250mm swing. Its motor is a $\frac{3}{4}$ horsepower (560W) four-pole capacitor-start induction motor. It is also reversible.

At first glance, it appears well within the 1500W capacity of the Speed Controller. The main and start windings are brought out to the on-off switch, which reverses one winding to reverse the rotation of the chuck.

Having access to both ends of the start winding overcomes the problem of the centrifugal switch re-engaging at low revs. It is easy to provide a relay to isolate the start winding as the motor speed is reduced. It is also easy to provide a relay to reverse the polarity of the start winding so the motor will start forward or reversed as required.

Even with the start winding isolation and direction taken care of, the subject motor would not start, as the Speed Controller tripped out with a fault indication. Over current was a prime suspect. Certainly, the instantaneous current on starting is enormous – at 230VAC 50Hz, it is about 50A. Starting at low speed, which means low voltage as well, should alleviate this.

Although the Controller permits a slow ramp-up from a low voltage, at slow speeds the winding reactance drops proportionately to the frequency, so the current does not necessarily drop as expected. This motor simply drew too much current for the Controller to start it.

There is also a possibility, as yet unverified, that with a capacitor in circuit, the Controller interprets a leading power factor as a short circuit, since in both cases it would see current increasing without a corresponding voltage increase.

Fortunately, the Controller itself provides the solution. It has a three-phase output. We can split the windings across two phases to keep each phase current within the maximum of the Controller, at least up to a certain size of motor. One phase is selected for the main winding. Of the other two phase voltages, one leads the main by 120° and the other lags by 120° .

Either of these should give sufficient quadrature current to the start winding to create a rotating field, but it is necessary to remove the start capacitor and short its connecting leads together. If the output terminals of the Controller are labelled A, B and C, the main winding is connected between A and C and one end of the start winding is connected to B.

The other end of the start winding can be experimentally connected to A, then to C. The better of these options is typically the one that starts to turn the motor at the lower voltage. It does not matter whether the motor starts in the forward or reverse direction. The direction of rotation can be controlled with the forward/reverse relay or a winding polarity reversal.

Fig.2 shows the connection of the motor to the Controller in this case. I found that this $\frac{3}{4}$ HP motor had to be accelerated with about a four-second ramp from 0-50Hz.

This is set by trimpot VR2 (RAMP) in the Controller. As the voltage is applied and the armature begins to rotate, it generates a back-EMF that reduces the current and gives room for more voltage to be applied, accelerating the armature further. The ramp voltage must not increase too fast for the armature to accelerate and generate the current limiting EMF.

Other motor configurations

What if both ends of the windings are not brought out, as is typical of a huge number of small, non-reversible capacitor start induction motors? Can such a motor still be controlled in the manner described above?

The answer in many cases is yes! Not only can such a motor be speed controlled, it can also be reversed. Fig.3 shows the two most likely motor configurations at left. In both cases, the start capacitor is removed and the wire that connects directly to one of the existing terminals is taped off and secured. The remaining wire is the new connection point for the start winding.

This wire, adequately insulated, is brought out of the capacitor chamber. This lead and the previously assigned phase and neutral leads connect to the three-phase output of the Speed Controller, as shown at right. Reversal of the direction of rotation is achieved by swapping any two phases.

Changing a faulty start capacitor is routine maintenance on induction motors – hence, removing the start capacitor and installing the two-phase wiring should be well within the capability of any builder with the knowledge and skill to build the Controller. Doing so opens up a greatly increased number of applications for variable speed operation.

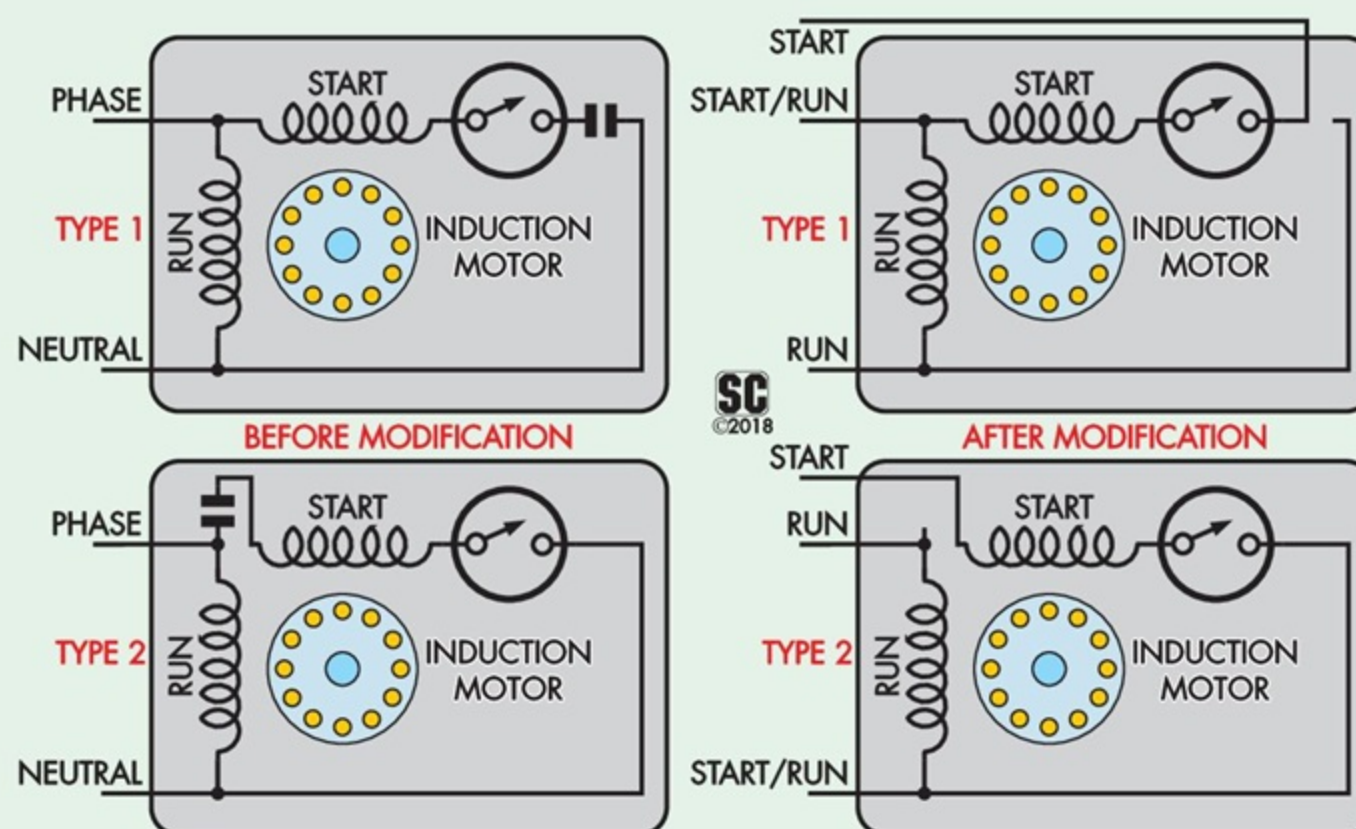


Fig.3: for motors where separate connections are not provided for the start winding, the start capacitor can be removed and one of its connections brought out to provide the connection to the start winding.

Win a Microchip dsPIC33CH Curiosity Development Board

Practical Electronics is offering its readers the chance to win one of two Microchip dsPIC33CH Curiosity Development Boards (DM330028).

The dsPIC33CH Curiosity Development Board is a cost-effective development and demonstration platform for the dsPIC33CH128MP508 family of dual-core high-performance digital signal controllers. The dsPIC33CH has one core designed to function as a master, while the other is designed as a slave. The slave core is useful for executing dedicated, time-critical control code, while the master is busy running the user interface, system monitoring and communications functions, customised for the end application. The dsPIC33CH is specifically designed to facilitate independent code development for each core by separate design teams and allows seamless integration when they are brought together in one chip.

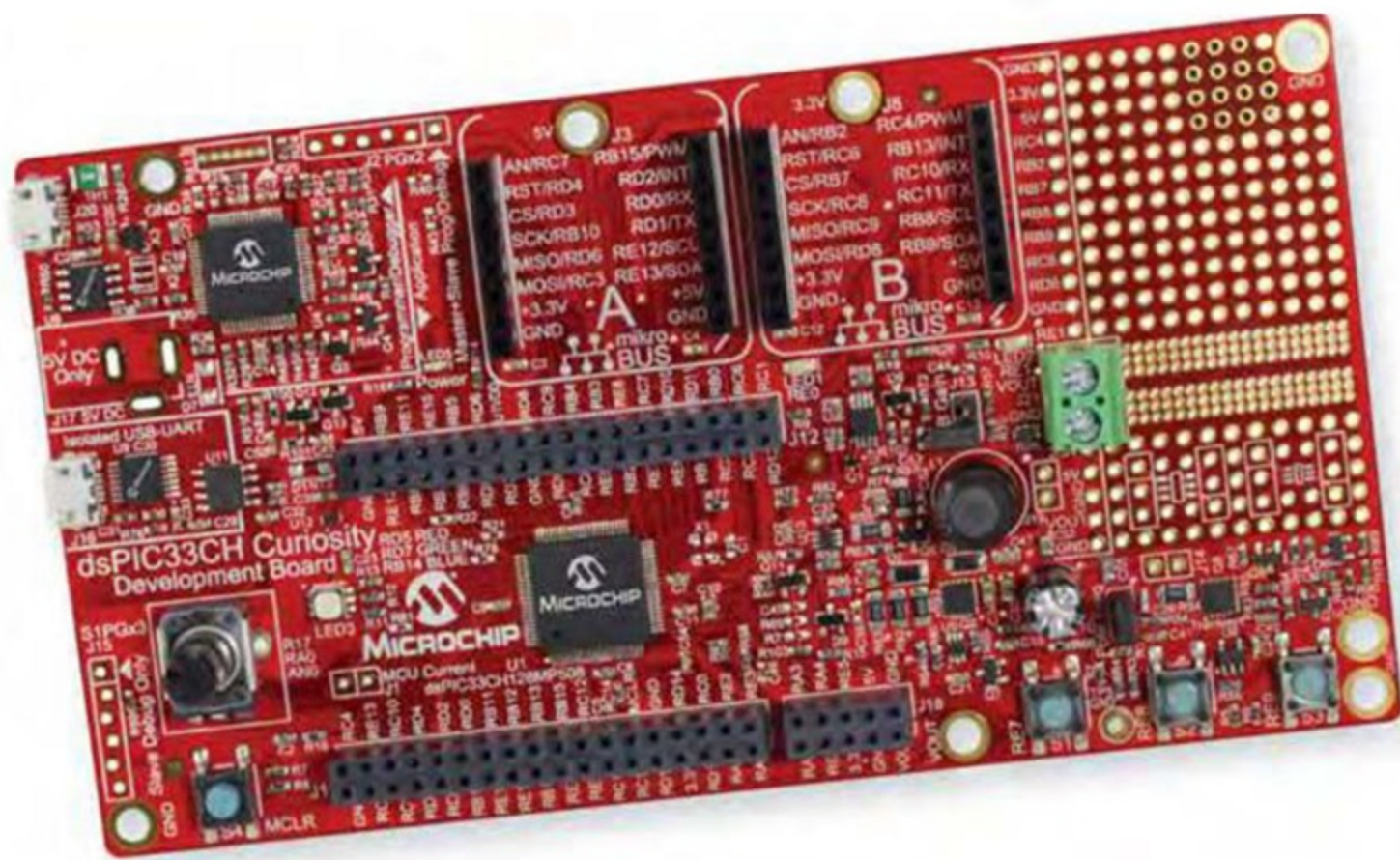
The board is designed to take full advantage of Microchip's MPLAB X IDE and includes an integrated programmer/debugger. The board requires no additional hardware, making it a perfect starting point to explore the dsPIC33CH dual-core family.

Supported by Microchip's MPLAB development ecosystem, including Microchip's MPLAB Integrated Development Environment and MPLAB Code Configurator, the dsPIC33CH Curiosity Development Board is a cost-effective and flexible platform enabling customers to rapidly create a feature-rich prototype.

The board supports the dsPIC33CH Plug-in Module for motor-control platforms, available for Microchip's MCLV-2 and MCHV 2/3 systems. The dsPIC33CH PIM for general-purpose platforms is now also available for the Explorer 16/32 development board.

**Worth
\$35.00
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How to enter

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The closing date for this offer is 30 September 2019.

May 2019 winner

Charles Sparey and
Jens Peter Nielsen

They each won a
Microchip AVR-IoT WG
Development Board
worth £22.30



SUPER-PORTABLE TWIN DIPOLE GUITAR/PA SPEAKER

by
Allan-Linton Smith

This guitar/PA speaker is easy to build and really portable. It's also **LOUD** and sounds great. When on stage, you can project plenty of sound to the crowd while still being able to hear your own playing (no foldbacks needed). If you build it using our recommended drivers (as used by Hendrix and Slash), it has a mellow, old-fashioned tone. But you can also use different drivers for a more modern, harder sound.

Because of the way this speaker is designed, it can be folded flat for easy transport and can be built by anyone with only rudimentary carpentry skills and tools.

You can easily build it in a day, with a perfect finish and a professional appearance. You can even choose from a range of colours to suit your style or band!

Choice of drivers

One of the great things about this design, besides the advantages laid out above, is that you can choose from a range of drivers which have their own unique sound.

And because it's a twin-driver rig, you can use two different ones (as we have done), giving you the option of three different tones: upper driver only, lower driver only or both together.

The drivers we are recommending come from a series with a long history. They have been used by some people you may have heard of, including Angus Young, Jimi Hendrix, Slash, Eric May, Brian Gibbons and Eddie Van Halen.

While you can use just about any two 12-inch (30cm) drivers, we are recommending Celestion units in this project for several reasons.

One, they are good quality. Two, they are designed to provide a tone to suit an electric guitar. And three, there are 22 different drivers in the series to choose from, each with their own unique sound profiles, power levels and efficiencies.

This includes four from Celestion's Heritage series, three from the Alnico series, one from the Signature series (the Eddie Van Halen), 14 from the Classic Series and two from the Originals series. You can see a list of suitable drivers at: <http://bit.ly/pe-sep19-cel>

For many of the drivers, audio samples of guitar playing are provided, allowing you to get an idea of what it sounds like before purchase. Note that this list includes some drivers which are not suitable; ie, those which are not 12 inches (305mm) in diameter or those which are not available with a 15Ω or 16Ω nominal impedance.

The maximum power level of the suitable Celestion drivers ranges from 15W to 100W. Our unit uses the G12M Greenback

and Vintage 30 drivers, which are rated at 96dB @ 1W, 20W maximum and 100dB @ 1W, 60W maximum respectively.

Since these are from the Heritage and Classic series, they give a laid-back sound with plenty of mid bass and high-end. If that isn't your bag, see below for some other options.

The G12M was a favourite of Jimi Hendrix; he used a whole raft of them to handle his powerful riffs and it was also used extensively by Eddie Van Halen. On the other hand, the Vintage 30 has been used by Slash, Steve Stevens and Peter Frampton.

These drivers are designed to be rugged and use paper cones with a small amount of doping. They are also very sensitive and are generally rated at 96-100dB/watt at one metre because the lead guitar has to be loud!

Not your grandpa's guitar speaker

Traditionally, guitar speakers consist of a small wedge-shaped box with one to four drivers arranged along the front. These generally have no acoustic filling, bracing or damping and often have a resonant or 'boxy' sound that accentuates notes played at the resonant frequency of the box. This gets boring pretty quickly.

Our aim for this project was to provide the guitarist with a sound which specifically suits their instrument. That's quite a personal thing, but since the enclosure is customisable, that's not a problem.

We settled on a 'dipole' arrangement of two 12-inch drivers which can be used individually or together, depending on whether you're practising or performing. If you have multiple electric guitars, you may find that some work better with one driver while others sound best with the second driver.

The speaker's 'angle of attack' can also be easily adjusted to suit different venues. The dipole completely removes cabinet colouration so that the resulting sound is quite neutral across the entire audio spectrum. Basically, you're just hearing the characteristics of the driver, which is determined by the manufacturers.

And since the drivers we're using are specifically intended for lead or rhythm guitars, that's the ideal situation.

The sound from the dipole setup is not terribly directional; that is to say, it doesn't much matter where you point it because the sound is much the same at the back, front or sides.

So not only is it its own foldback speaker, the crowd will enjoy your gig regardless of whether they are right in front of the speaker or off to the side.

Testing it out

We had our resident guitar player, Bao Smith, test the speaker and he confirms that it has the most important property that any guitar speaker needs: it can definitely make a lot of noise and sounds good doing so!

Allan also had his guitar-crazy mate Marcus test it out in an extended jam session, using a Gibson guitar and 30W valve amplifier. Afterwards, he commented: 'It's great for a lead guitar and has plenty of volume which will rise above the other instruments in my band.' (We had to wear hearing protection while he was playing.)

I made an efficiency measurement with both speakers connected in parallel and got a result of 105dB/watt at one metre – that's pretty amazing.

We have made some performance measurements, but remember that this speaker is *not intended for Hi-Fi use*, so we aren't looking for ultra-low distortion. In fact, many guitar players like having plenty of distortion!

A plot of distortion against frequency for the two drivers in parallel is shown in Fig.1 and you will notice that distortion is very high below 80Hz and above 7.5kHz. That's because these frequencies are outside the response of the drivers and so the sound level is dropping off quite significantly. Anything below about 60Hz has too great a drop-off to be audible. There are some spikes at intermediate frequencies (eg, around 320Hz) but these could be measurement artefacts as they do not seem to be audible.

Fig.2 shows the frequency response of the two individual drivers plus the combined drivers. These are very 'noisy' measurements due to the fact that the microphone has been placed some distance away from the speaker in order to provide a realistic result. But room resonances and interference then affect the readings.

The 'near-field' responses, taken with the microphone right in front of the two drivers, do not suffer from this. In

Features and specifications

Drivers:	Two 12-inch Celestion loudspeakers (recommended)
Weight:	about 17kg
Efficiency:	100dB/1W@1m
Total cost:	~£200 with the recommended drivers
Drive options:	top only, bottom only or both

Simple construction

Easy to fold up and transport

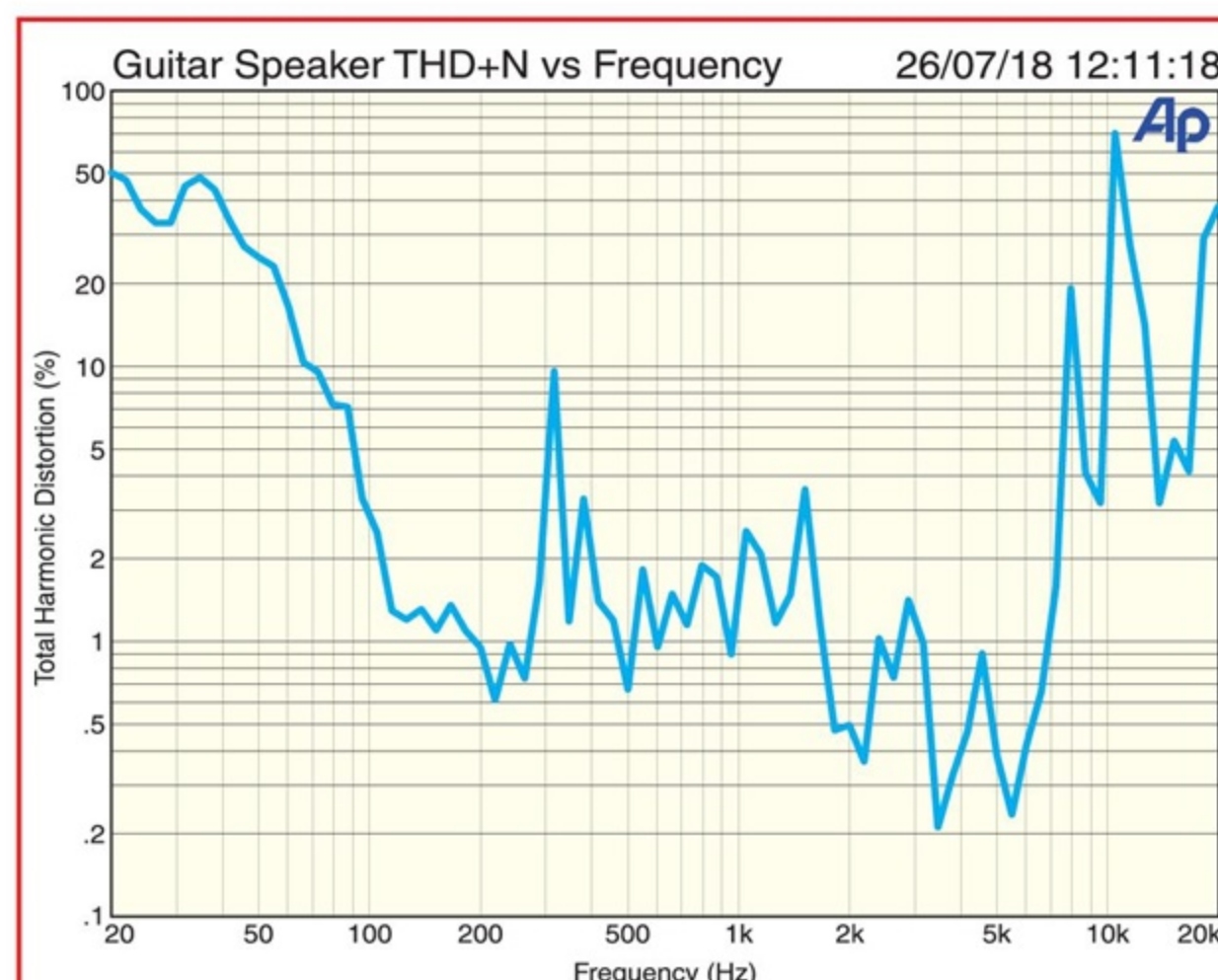


Fig.1: the distortion level is not particularly low, but sometimes that's what a guitar player actually wants!

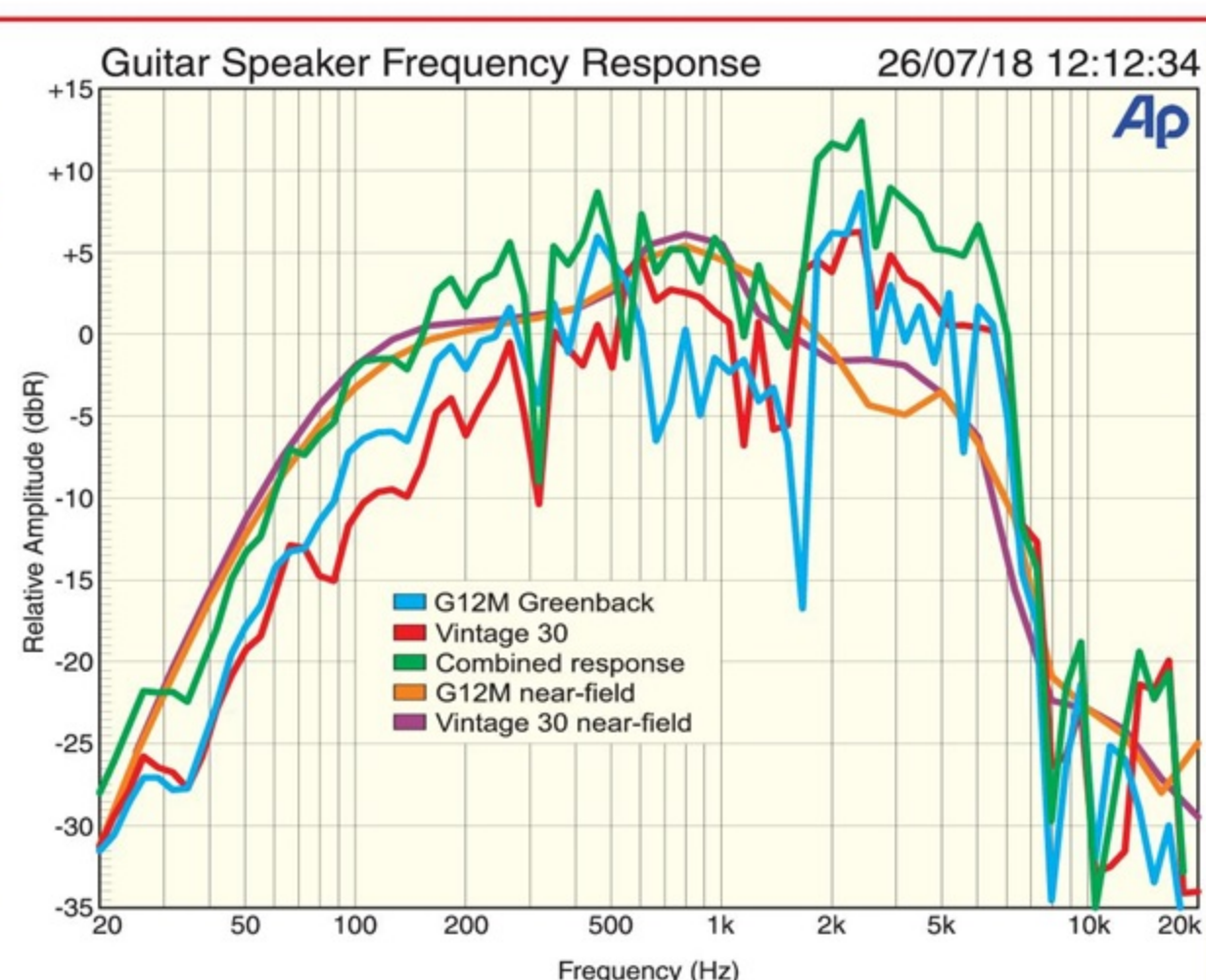


Fig.2: the usable frequency response is from 80Hz to about 8kHz – more than enough for guitar and even PA use.

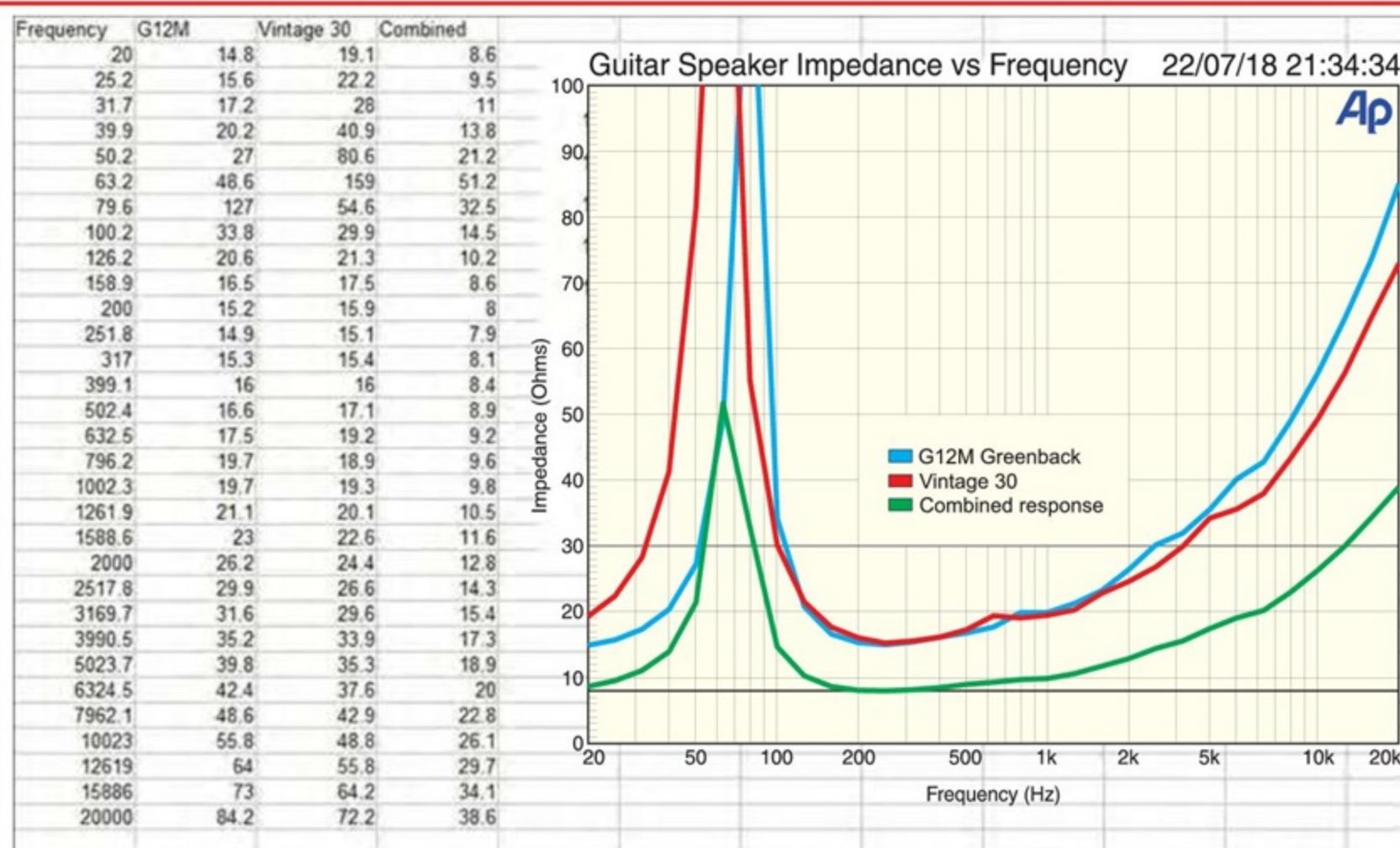


Fig.3: the combined impedance from both drivers barely dips below 8Ω, so should not be a problem for the vast majority of amplifiers (even 'Hi-Fi' amps). We even succeeded in driving it from the headphone output of a guitar amp.

any case, you can see that all of the responses start to fall off below about 100Hz and above 6-7kHz.

That's a pretty wide range for a single driver. The lowest string on a six-string guitar is normally tuned to 82Hz (E) while the highest fret on the highest string is normally tuned to 1047Hz (see fret table).

The speaker response covers this entire range of frequencies with plenty of room on top for harmonics. Of course some of the more popular alternative tunings (drop-D) have lower frequencies (73Hz).

Speaker impedance

We're using the 16Ω version for both speakers, so when driven in parallel, they present a modest 8Ω load to the amplifier. The impedance of each combination of drivers is shown in Fig.3 and this shows that when driving both in parallel, it barely dips below 8Ω.

they require output transformers, they usually have several output impedance taps, which may influence your selection.

Choosing an amplifier

The reason guitarists tend to prefer valve amplifiers is for the way they sound when they're overdriven, as a valve amplifier will typically sound better than a solid-state one when driven to its limit. This speaker works really well with valve amplifiers because of the fact that it has a relatively high impedance and because of its high efficiency, which suits the relatively low power output of a typical valve amplifier.

But you certainly can use it with a solid-state amplifier and it doesn't necessarily have to be a guitar amp. As long as you have appropriate signal conditioning (ie, some form of guitar preamp), you could use a Hi-Fi or PA amplifier too. You don't even need to use it with a guitar! You could

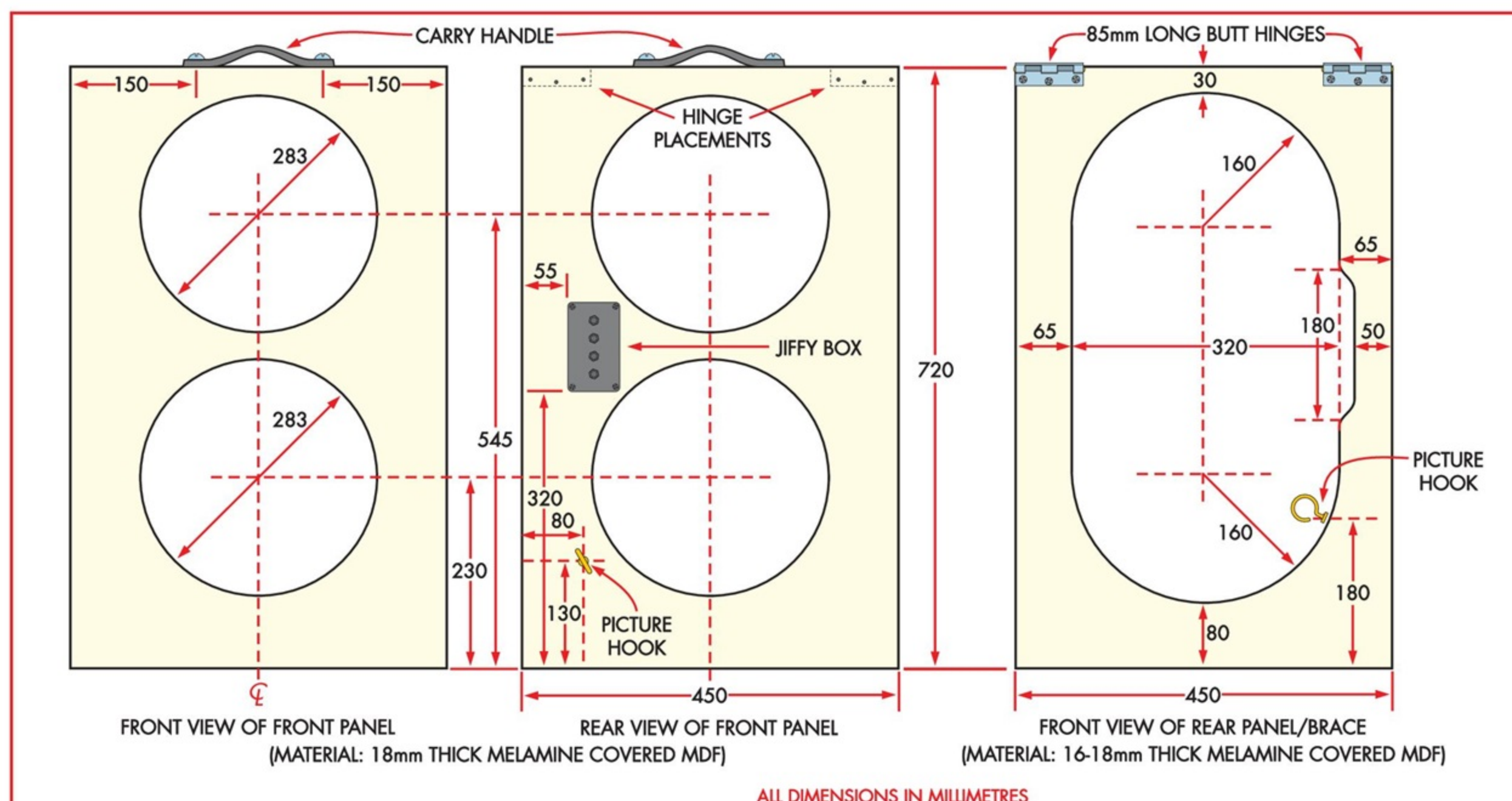


Fig.4: cutting diagram for both the front and rear of the dipole speaker panels, which are joined at the top with butt hinges to form an A-frame. We used kitchen door panels, but chipboard or MDF would be fine.



The two 12-inch drivers we're recommending, both from Celestion. At left is the G12 M Greenback; at right is the Vintage 30. You *can* substitute other drivers, but we can't guarantee that they will perform as well as these do.

use it with a different type of electric instrument like a synthesiser, bass or harpejji, or you could connect a microphone and a suitable preamp/amplifier and use it as a portable PA system.

Sourcing the timber frame

The two halves of the 'sandwich board' are made from kitchen cabinet doors which measure 720x450x18mm. We purchased these in gloss white but there are many other colour options and finishes. Why not try piano black, or be daring and go for a 'seductive red' in full gloss!

You could also use plywood, MDF or any other material as long as it is at least 18mm thick. The rear support is not critical and 16mm thick material (eg, melamine-coated fibreboard) is suitable. The two halves are attached at the top with two 85mm stainless steel hinges.

Junction box operation

The circuit for the junction box is quite simple, as shown in Fig.5. It uses just four DPDT switched stereo jack sockets and some wiring to perform all the necessary functions. The

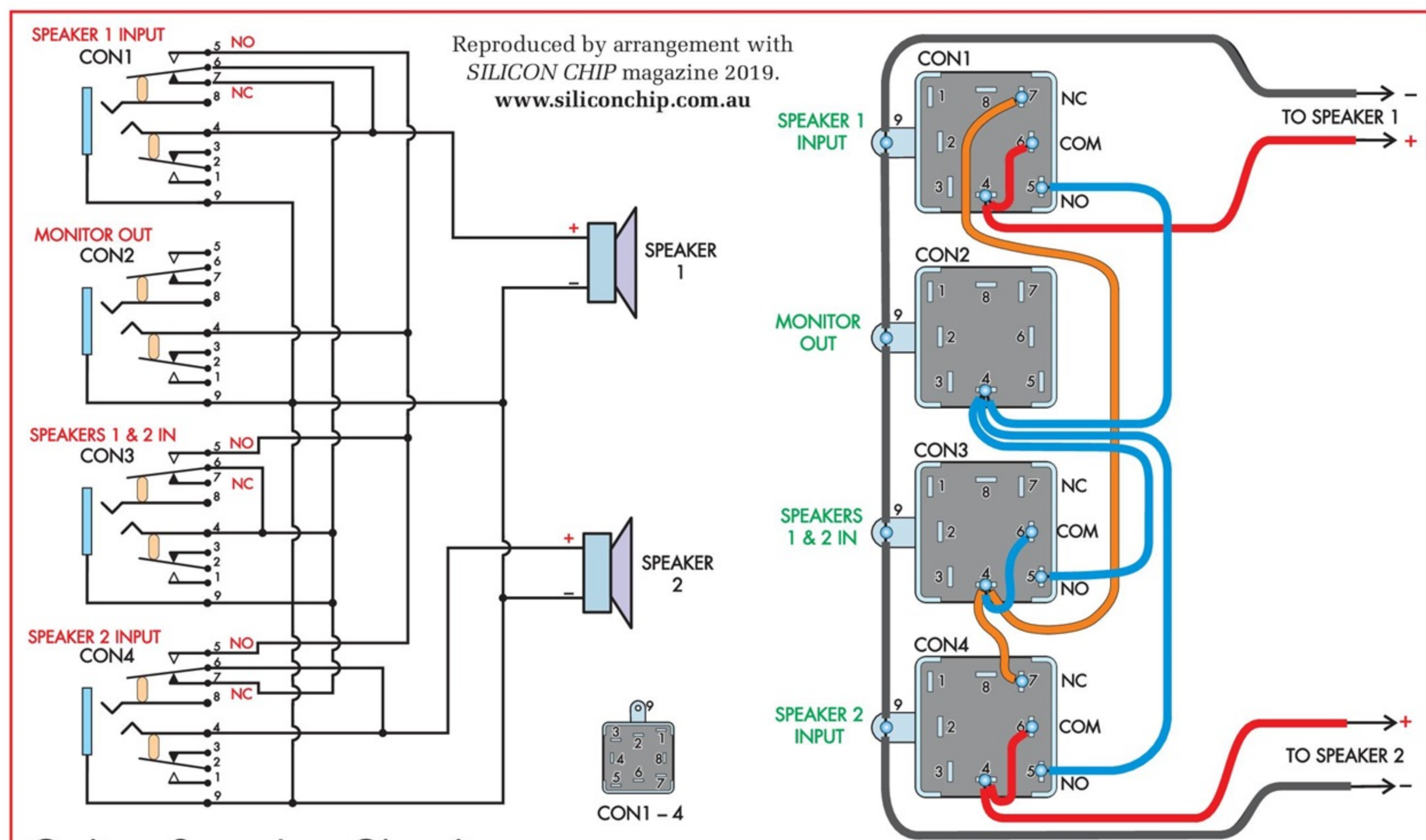
sleeves of all four sockets are joined together to form a common ground connection, which is wired directly to the negative end of both drivers. All the signal routing is done to the positive side of the drivers.

Each socket consists of the three usual contacts for a stereo socket – tip, ring and sleeve – plus two insulated double-throw switches which are actuated when a plug is pushed past the tip and ring contacts respectively. These switches are used to route the connections to provide the required functions.

CON2 is an output socket to go to a monitor amp (eg, driving headphones worn by the player) and the switch at pins 5, 6 and 7 of the other three sockets are connected such that when you insert a plug in any of those other sockets, its tip connection (at pin 4) is routed to the tip of the monitor socket, via the normally open contacts of the switches (pin 5). This means it receives the input signal regardless of which driver(s) are being driven.

By the way, never plug your headphones directly into CON2 if you value either your headphones or your hearing!

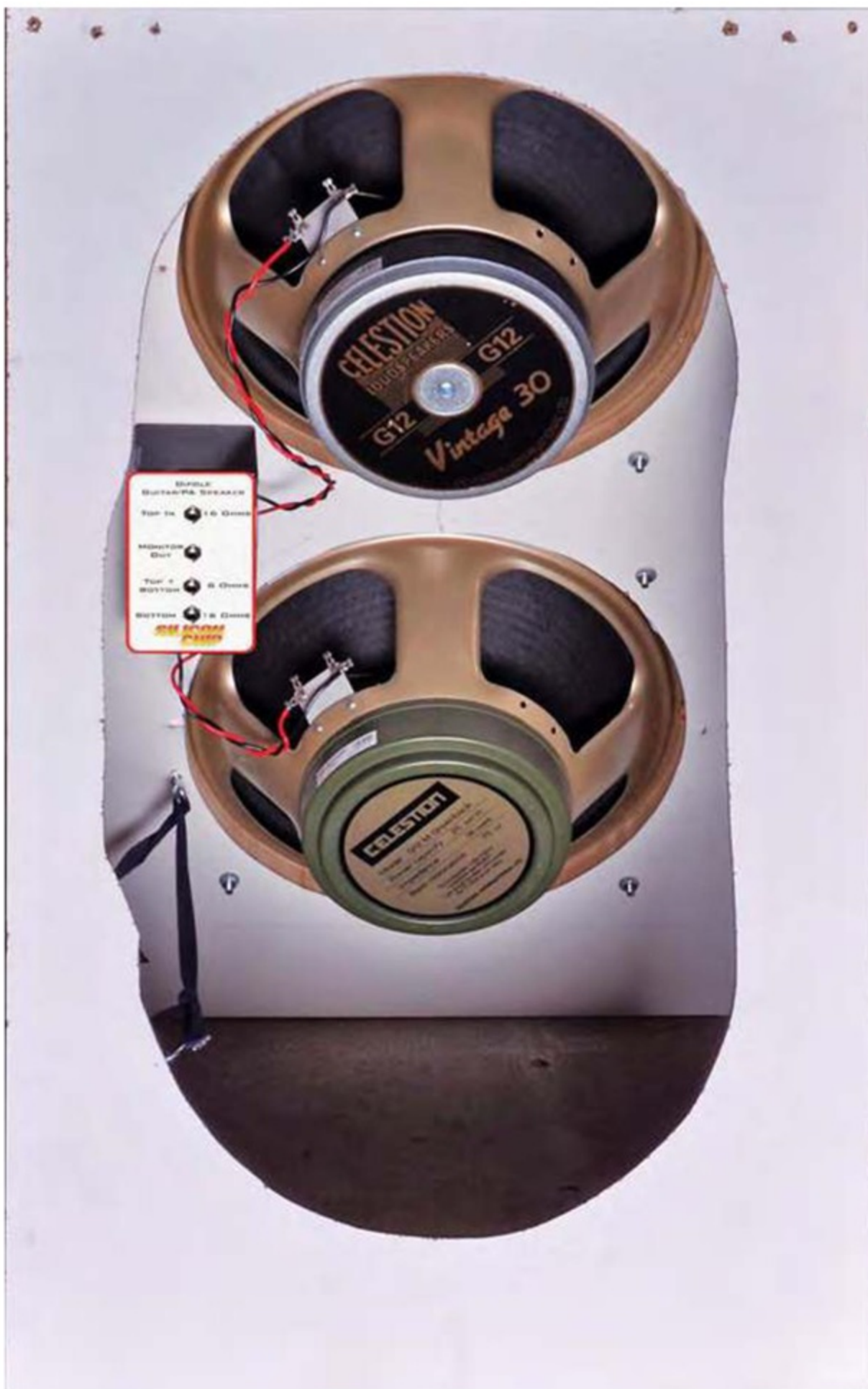
The normally closed half of the three double-throw switches is used to apply the signal to the correct loudspeaker, based on which socket you have inserted the plug into.



Guitar Speaker Circuit

Fig.5: the circuit is very simple, basically it is just the four 6.35mm sockets and some wiring between them and to the speakers.

Fig.6: and here's a pictorial view of that wiring. The labelling of the four input sockets coincides with the panel artwork shown in Fig. 7.



View through the rear panel, showing the two speaker drivers and input box secured to the front panel. (Its position is not important – just make sure the rear panel cutout is large enough to accommodate it when closed). You can also just see the cord which stops the front and back panels opening too far. (Yeah, we know – we could have made the rear panel cutout a bit straighter...)

If you plug into CON1, the tip connection is wired directly to the positive terminal of SPEAKER1 so signal flows to that driver. The NC terminal of that socket's switch at pin 7 is no longer connected to pin 6 so the signal does not flow to the other driver.

Similarly, if you plug into CON4, the tip connection feeds the signal to SPEAKER2 but the switch is disconnected from anything but the monitor socket and so the signal does not go to SPEAKER1.

But if you plug into CON3, the signal from the tip is instead fed to the NC terminals of the switches in both CON1 and CON4 and since nothing is plugged into those sockets, the signal then flows to the positive end of both SPEAKER1 and SPEAKER2 via pin 6 on those sockets.

Construction

The assembly process is straightforward and assuming you have the right tools on hand, you should be able to go from an assortment of parts to a finished speaker in a few hours.

You need to make two circular cut-outs in the front panel and one large rounded-rectangle shape cut-out in the rear panel. The details are shown in Fig.4. Start by marking the 283mm driver cut-outs in the front panel using a compass, then carefully cut out the circles using a jigsaw.

Note that if you are using kitchen cabinets or similar coated timber then you should cut them from the reverse side using a good quality, fine tooth jigsaw blade (preferably a new one!).

Use a similar process to cut the large hole on the rear panel. You can mark the two circles in the same manner, then join them using a long straight edge before making the cutout.

Lay the two panels end-to-end and mark out the drilling locations for the hinge attachment screws. Drill small pilot holes (again using masking tape to protect the front finish), then attach the hinges to both panels using 15mm countersunk wood screws and check that the two boards fold correctly. They should fold flat against each other.

The next step is to attach the drivers. This is easiest to do if you fold the assembly together and support it horizontally between two stable benches or other supports. Drop the drivers into the holes and rotate them so that the labels on the back will be right-side-up, then mark out the mounting holes.

Remove the drivers and drill these with a pilot drill bit, then reinstate the drivers and attach them with 10mm countersunk wood screws through the front of each surround and into the front panel timber.

Now place the grilles on top of the driver surrounds, arrange the supplied mounting brackets around the edge (equally spaced), as shown in our photos, and mark the required hole positions for these brackets. Then remove the brackets and drill pilot holes in those locations. Fix the brackets to the front panel using 20mm wood screws, ensuring that the grilles are held firmly in place.

You can now attach the handle to the top edge of the front panel, again by drilling pilot holes and then attach it with 40mm wood screws. Now is also a good time to stick the adhesive felt strips on the bottom of both panels, one at each end and one in the middle.

Next, drill a couple of pilot holes at corresponding points on the inside of the front and rear panels, so that you can screw in the cup hooks and then tie the cloth strap or cord between them, to limit how far the assembly will open. This prevents it from falling over when in use. Adjust the length of the strap until you are happy with the angle that the panels sit at when opened up.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Guitar	OPEN	F	F#	G	G#	A	A#	B	C	C#	D	D#	E	F	F#	G	G#	A	A#	B	C
	330	349	370	392	415	440	466	494	523	554	587	622	659	698	740	784	831	880	932	988	1047
	B	C	C#	D	D#	E	F	F#	G	G#	A	A#	B	C	C#	D	D#	E	F	F#	G
	247	262	277	294	311	330	349	370	392	415	440	466	494	523	554	587	622	659	698	740	784
	G	G#	A	A#	B	C	C#	D	D#	E	F	F#	G	G#	A	A#	B	C	C#	D	D#
	196	208	220	233	247	262	277	294	311	330	349	370	392	415	440	466	494	523	554	587	622
	D	D#	E	F	F#	G	G#	A	A#	B	C	C#	D	D#	E	F	F#	G	G#	A	A#
	147	158	165	175	185	196	208	220	233	247	262	277	294	311	330	349	370	392	415	440	466
	A	A#	B	C	C#	D	D#	E	F	F#	G	G#	A	A#	B	C	C#	D	D#	E	F
	110	117	123	131	139	147	156	165	175	185	196	208	220	233	247	262	277	294	311	330	349
Bass	E	F	F#	G	G#	A	A#	B	C	C#	D	D#	E	F	F#	G	G#	A	A#	B	C
	82	87	92	98	104	110	117	123	131	139	147	156	165	175	185	196	208	220	233	247	262
	Note and frequency in Hertz (approx.) for standard tuning.																				
	G	G#	A	A#	B	C	C#	D	D#	E	F	F#	G	G#	A	A#	B	C	C#	D	D#
	98	104	110	117	123	131	139	147	156	165	175	185	196	208	220	233	247	262	277	294	311

Fig. 8: we show this more for interest sake than anything else – it's the frequencies of each note when either a rhythm or bass guitar is tuned correctly. The dipole speaker as described here will handle notes down to about 80Hz.

Junction box assembly

The first step is to drill four holes down the centre of the Jiffy box lid and then enlarge them (using a stepped drill bit or tapered reamer) until the sockets are a good fit – not too loose.

The panel label (Fig.7) can be used as a template to space these holes.

Stick on the panel label and cut out the socket holes with a sharp hobby knife. You can print it and laminate it, then attach it using contact adhesive or silicone sealant. Or you could print it mirrored on transparent film and glue it on with the ink towards the lid, using a thin smear of clear silicone sealant.

You can also get adhesive-backed paper for inkjet and laser printers which you can simply cut out and stick on to the lid.

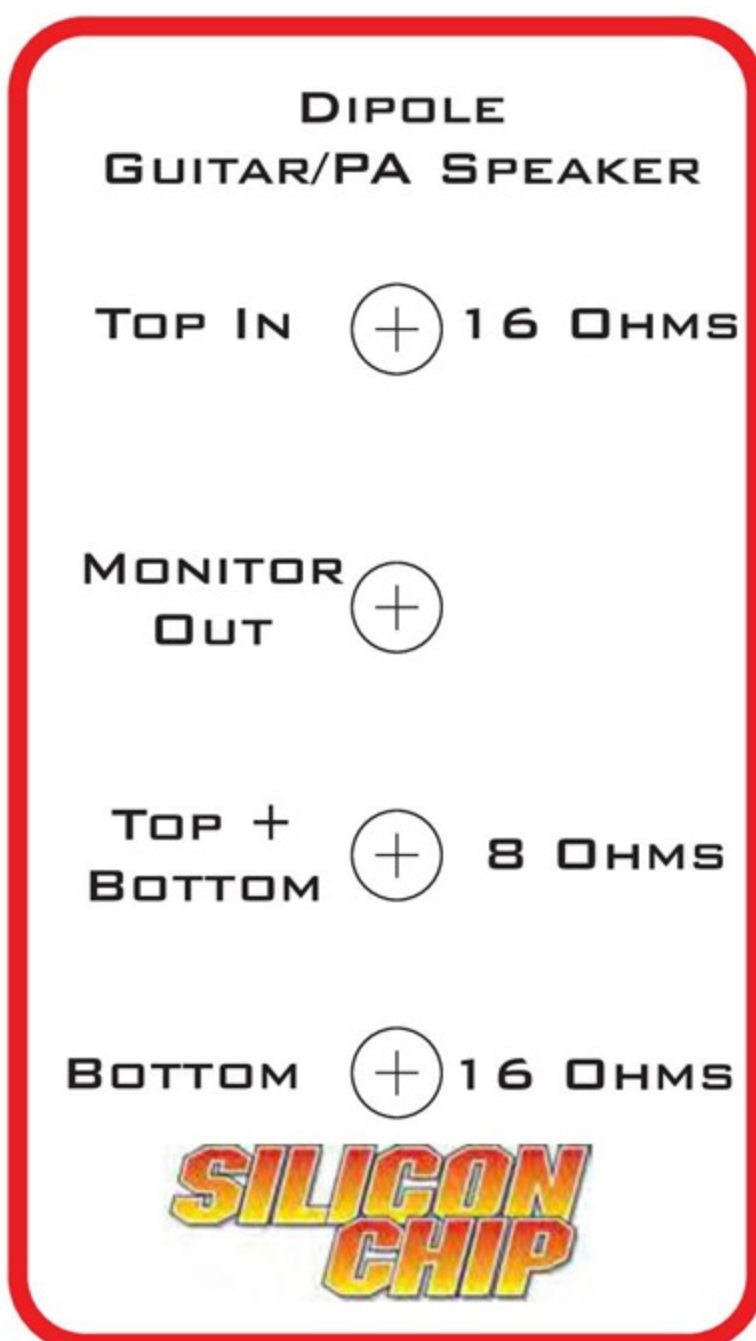


Fig.7: front panel artwork for the Jiffy box mounted alongside the speaker drivers. You can download it from the *PE* website to use as a drilling template for the four input sockets.



When you've finished your gig, simply unplug the amplifier, fold the two halves together and carry the speaker away. This photo shows why a large cutout is required on the rear panel (to enable you to fold the front and back flat).

Parts list – A-frame Guitar/PA Loudspeaker

- 1 16Ω Celestion Classic Series G12M Greenback 12-inch driver *and*
- 1 16Ω Celestion Classic Series Vintage 30 12-inch driver *or*
- 2 8Ω 12-inch 100W polypropylene woofers [Altronics C3070] (see text)
- 2 12-inch metal speaker protection grilles with mounting brackets [Altronics C3712]
- 2 720x450x18mm kitchen cabinet doors or plywood/MDF sheets (see text)
- 2 85mm stainless steel butt hinges
- 1 slim carry handle [Altronics C3660, Jaycar HS8022]
- 8 No.3 x 10mm countersunk head wood screws (for mounting drivers)
- 4 No.3 x 20mm pan head wood screws (for grilles)
- 12 No.4 x 15mm countersunk head wood screws (for hinges)
- 2 No.3 x 40mm pan head or countersunk head wood screws (to suit handle)
- 2 No.4 x 10mm pan head wood screws (to mounting Jiffy box)
- 2 19mm cup hooks
- 1 350mm long cloth or rubber strap with loops at each end *or*
- 1 400mm length of small diameter rope/blind cord
- 4 DPDT mono or stereo 6.35mm jack sockets, chassis-mounting [Jaycar PS0182, Altronics P0072]
- 6 heavy-duty adhesive 20 x 50mm felt strips (or larger strips cut to size)
- 1 UB3 bulkhead Jiffy box (130 x 67 x 44mm [not including flanges])
- 1 adhesive panel label for Jiffy box lid
- 1 1m length of speaker cable (or two 1m lengths of red and black heavy duty hookup wire)
- Various lengths of heavy-duty hookup wire (see Fig.6 for suggested colours)

With the label in place, attach the sockets using the supplied nuts and solder short lengths of heavy-duty hookup wire between the sockets – see Fig.6. This makes the connections as shown in the circuit diagram, Fig.5. Note that several amps can flow through this wiring if you're driving the speaker hard, hence our recommendation to use heavy-duty wire.

You can use the same wire, twisted together, to connect to the drivers. That's how the prototype was built. Or you could use figure-8 speaker wire, which would be a little neater. Solder the four speaker wires to the socket terminals as shown in Fig.6, then drill a small hole in the side of the Jiffy box and feed the speaker wires out through this hole, then solder them to the tabs on the drivers.

Make sure that the wires for SPEAKER1 go to the top driver and the wires for SPEAKER2 go to the bottom driver and don't get the positive and negative wires mixed up or you will get sound cancellation when using both speakers at the same time.

Next, drill a couple of holes in the Jiffy box base and two corresponding pilot holes in the back side of the front panel. You can then feed a couple of short wood screws through the inside of the Jiffy box and into the holes on the panel, then screw the lid onto the box and the whole assembly should be firmly attached to the speaker. Refer to the photo opposite to figure out the best location for mounting this box.

That's it – your speaker is finished. Now all you have to do is connect a lead from your guitar amplifier's external output socket to one of the three input sockets on the Jiffy box and you're ready to jam!

Arduino NFC Shield



This low-cost NFC (Near-Field Communication) shield for Arduino uses the same technology as RFID and contactless payments. It allows just about any Arduino board to read data from NFC/RFID tags or cards, or write data to certain devices. You can also exchange data with other NFC devices, including many smartphones.

This shield, plus an Arduino module, could be used as the basis for a number of useful devices – for example, to unlock a door using an access card, to monitor the passage of stock or other items on a conveyor belt, to transmit business card information to customers' smartphones, and so on. But before we explain how it works, we'll explain how RFID and NFC work.

NFC, or Near-Field Communication, is a set of protocols that enable two electronic devices to exchange data by bringing them within about 40mm of each other.

Communication is by electromagnetic induction; ie, coupling signals between loop antennas in each device. In effect, when the two antennas are brought within 40mm of each other they form an air-cored RF transformer.

NFC involves low-power RF signals with a carrier frequency of 13.56MHz, in one of the globally available and unlicensed ISM (industrial, scientific and medical) bands.

One of the devices involved in NFC communication can be passive, ie, with no onboard power source. This is typically the case with RFID (radio-frequency identification) tags and smart cards.

In this situation, the device that is powered powers the circuitry in the passive device via the energy of the 13.56MHz RF carrier. The passive device then 'replies' by modulating

the carrier, with the modulated signal picked up by the active device.

RFID technology was developed in 1983 by Charles Walton. Sony and Philips agreed to establish a compatible specification and this was approved as an ISO/IEC standard in 2000 (ISO/IEC 14443). The passive tags and cards used for RFID typically store between 96 and 8192 bytes of data, which can be read (and in some cases, written) using the RFID protocol.

Nokia, Philips and Sony established the NFC Forum in 2004. It is a non-profit industry association which promotes the implementation and standardisation of NFC technology to ensure interoperability between devices and services.

NFC provides the same functions as RFID but also allows for communications when both devices are powered. In this case, power is not transferred using the carrier and the two devices can exchange data in an ad-hoc peer-to-peer fashion.

The standard defining NFC is ISO/IEC 18092. This technology is now found in all manner of smartphones and other portable devices.

Sony's FeliCa RFID system includes dynamic encryption for increased security. It was considered as part of the ISO/IEC 14443 RFID standard, but in the end was not included. However, some of the principles used by FeliCa ended up being used as part of the later NFC standard.

Three different data exchange rates are in current use by NFC devices: 106kb/s, 212kb/s and 424kb/s. If an active device transfers data at 106kb/s, it uses modified Miller coding with 100% modulation. Miller coding is a type of Modified Frequency Modulation known as 'delay encoding'. This is similar to NRZ (non-return-to-zero) encoding, but with less power radiated at lower frequencies.

For the higher data rates, Manchester coding is used, with a modulation ratio of 10%. Manchester encoding is another method of turning a bitstream into a symmetrical AC signal and is also used for transmitting digital audio data (S/PDIF).

Elecrow's NFC shield

The Elecrow ACS53201S NFC shield measures 69 x 53mm (including the loop antenna) and it plugs directly into an Arduino Uno or Mega 2560, or one of the many compatible modules. It derives its power from the Arduino and even comes with a passive keyring NFC tag for testing (see lead photo).

At the heart of the shield is the NXP/Philips PN532 NFC controller IC. The internals of this IC are summarised in the simplified block diagram (Fig.1). It's based around an NXP 80C51 microcontroller (upper right), which includes 1KB of RAM (working memory) and 40KB of ROM (for storing the firmware).

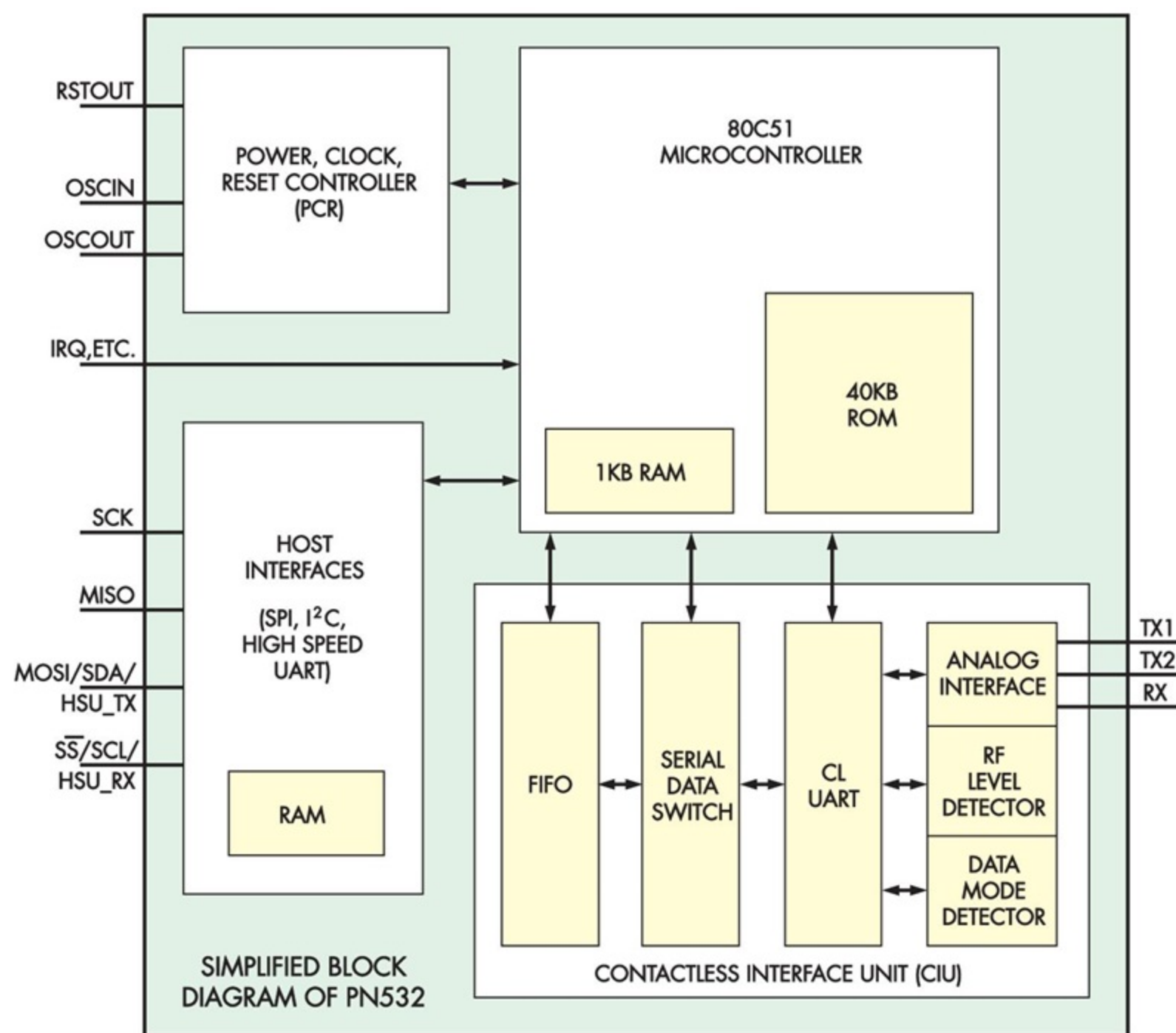


Fig.1: simplified block diagram for the PN532 controller IC. The chip is based around four sections: an NXP 80C51 micro (an old design!), NFC communications block, serial block and power/clock/reset controller.

The other main sections are the contactless interface unit or CIU (at lower right) which handles the actual NFC communication, and the host interface section at lower left, which handles communication with the host computer or controller (in this case, the Atmel micro on the Arduino board).

The host interface section can be configured to communicate via SPI (serial peripheral interface), I²C (inter-IC serial communication) or a high-speed UART (HSU; ie, serial) connection. But note that the PN532 chip used in the Elecrow NFC shield has been configured for SPI only.

Fig.2 shows the full circuit of the Elecrow NFC shield, plus a block diagram of an Arduino host at upper left.

The PN532 device (IC1) connects to the NFC loop antenna at top right via the TX1, TX2 and RX pins and a network of passive components. These include inductors L1, L2, various capacitors and a few resistors. These are used for impedance matching, to make the antenna resonant at the required frequency and to filter out unwanted signals.

IC1 uses a 27.12MHz crystal (X1) to generate its internal master clock and divides this by a factor of two to produce the NFC carrier frequency of 13.56MHz.

Although IC1 can operate from supply voltages of 2.7-5.5V, in the Elecrow shield it is powered from a 3.3V regulated supply. This is derived from the

Arduino's 5V supply via REG1, an MIC5205-3.3 LDO (low dropout) regulator. This is separate from the 3.3V rail from the Arduino because IC1 can draw up to 200mA when transmitting, which could overload the regulator on the Arduino.

This means that level translation is necessary on the SPI signal lines between IC1 and the Arduino. That's provided by IC2, a 74LV4T125 quad buffer translator. Three of IC2's buffers are used to translate the logic levels of the MOSI, SCK and MISO signal lines, with the fourth buffer unused. IC2 is also powered from the +3.3V supply from REG1.

The only other components on the board are a number of bypass and filter

capacitors for IC1, IC2 and REG1, a pull-up resistor on pin 38 of IC1 to enable it, and a capacitor and resistor connected to the V_{MID} pin of IC1 (pin 9), which is used to DC bias its RX pin (pin 10) to half supply.

Note that Jaycar sell a similar NFC Shield, made by 'linksprite' (Cat XC4542). While not identical to the Elecrow shield, it is compatible and we have tested it successfully with the same software.

Arduino software

Luckily, Elecrow has made the software side of things quite easy by making available an Arduino library written specifically for communicating with the PN532 via the SPI port. The library can be downloaded from the Elecrow website in a zip file called **PN532_SPI.zip** (see Links panel).

This can be made available for use in the Arduino IDE by clicking on the Sketch menu and then on the Include Library → Add .ZIP Library menu option. Select the ZIP file that you have downloaded and it will be added to the IDE's library list. The library comes with six example sketches, named:

writeMifareMemory
readMifareTargetID
readMifareMemory
readAllMemoryBlocks
PtoPTarget
PtoPInitiator

'Mifare' is another way of referring to passive NFC tags and cards. The 'PtoP' part of the last two sketch titles is short for 'peer to peer' and indicates that these sketches are used for NFC communication between two active devices.

I tried opening and running the first four of these example sketches with the Elecrow NFC shield connected to both an Arduino Uno and a Mega 2560. In each case, I tested it with both the keyring tag that came with the shield and also with an NFC card that came with another NFC/RFID reader.

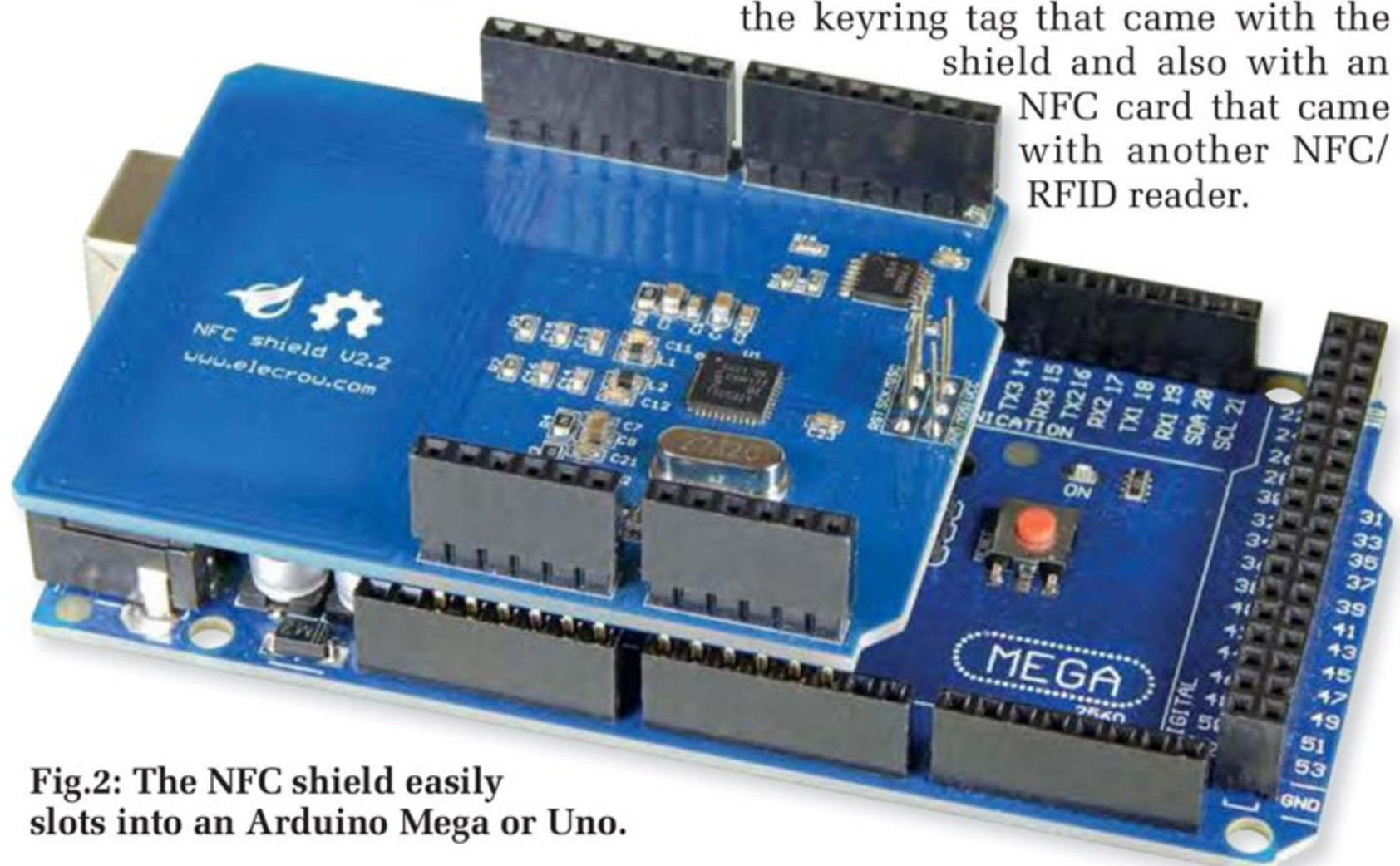
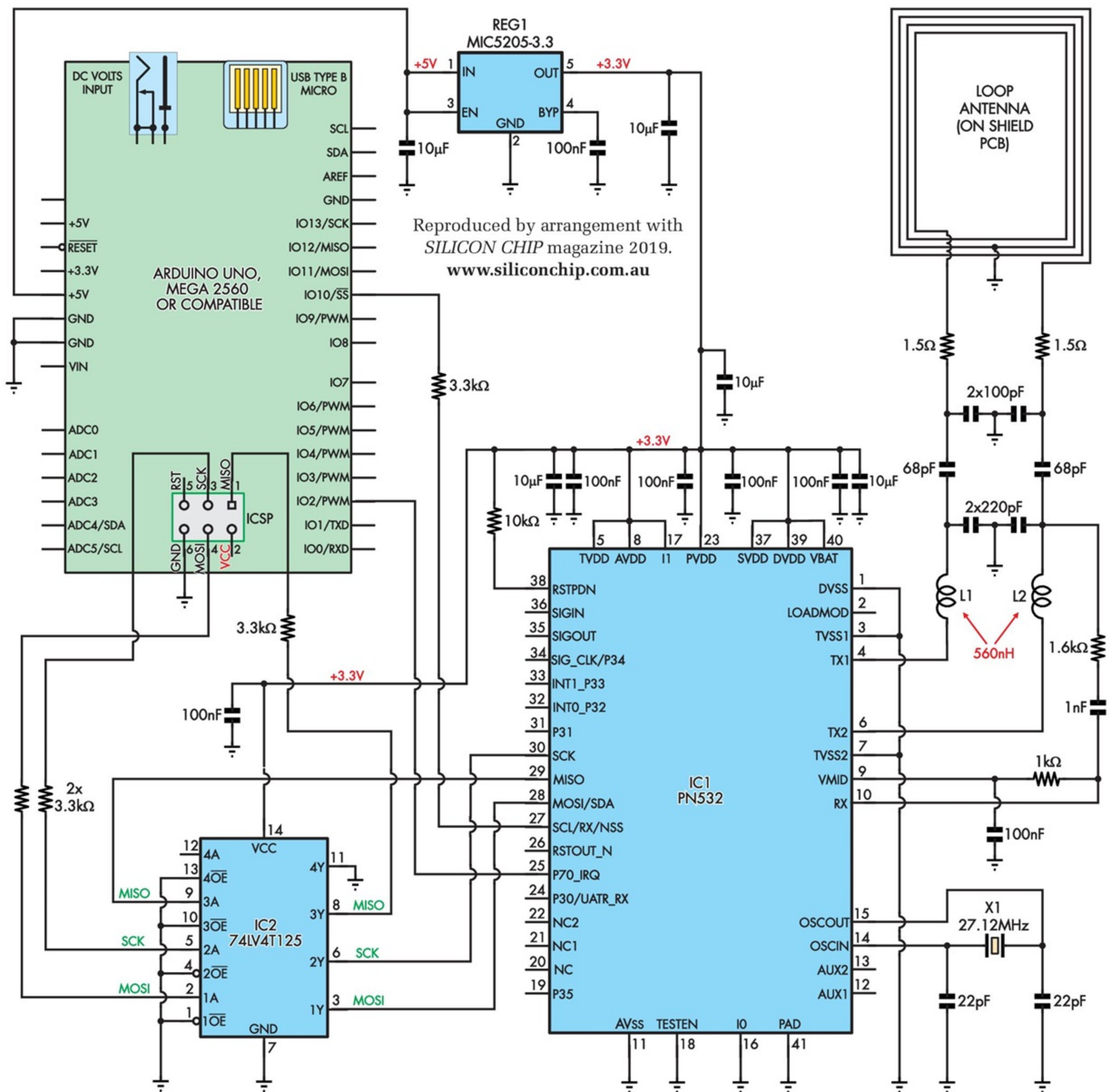
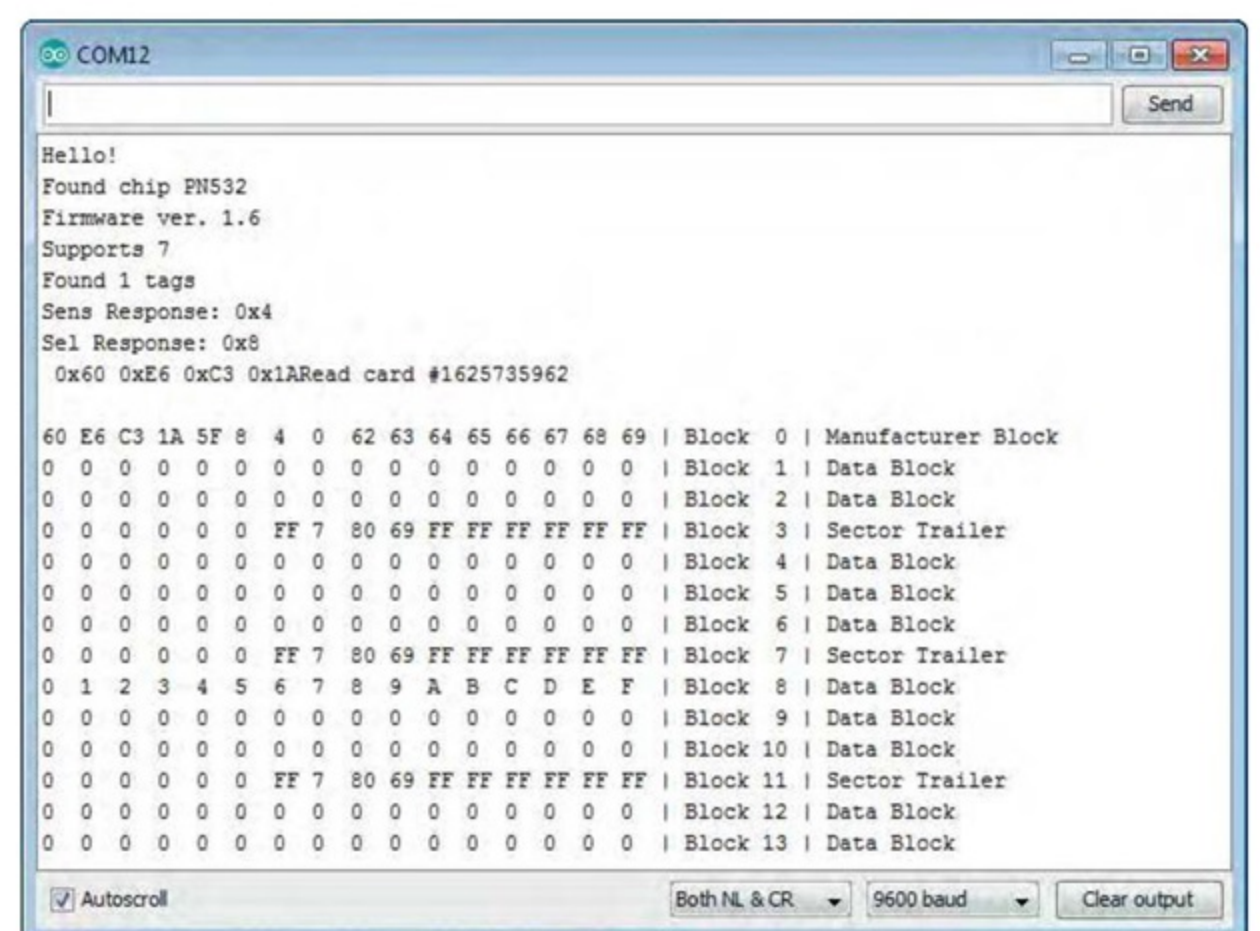


Fig.2: The NFC shield easily slots into an Arduino Mega or Uno.



Elecrow ACS53201S NFC Shield

Fig.2: complete circuit diagram for the Elecrow ACS53201S near-field communication (NFC) shield, and wiring diagram for the shield with an Arduino (or similar) board.



Each time it worked exactly as expected and I was able to read data from and write data to both passive devices with no problems.

You can get an idea of how the example sketches work from the screen grabs shown above. Both grabs are of the Arduino IDE's

Serial Monitor. Screen 1 shows the output when reading the card first and then the keyring tab, using the **readMifareMemory** sketch.

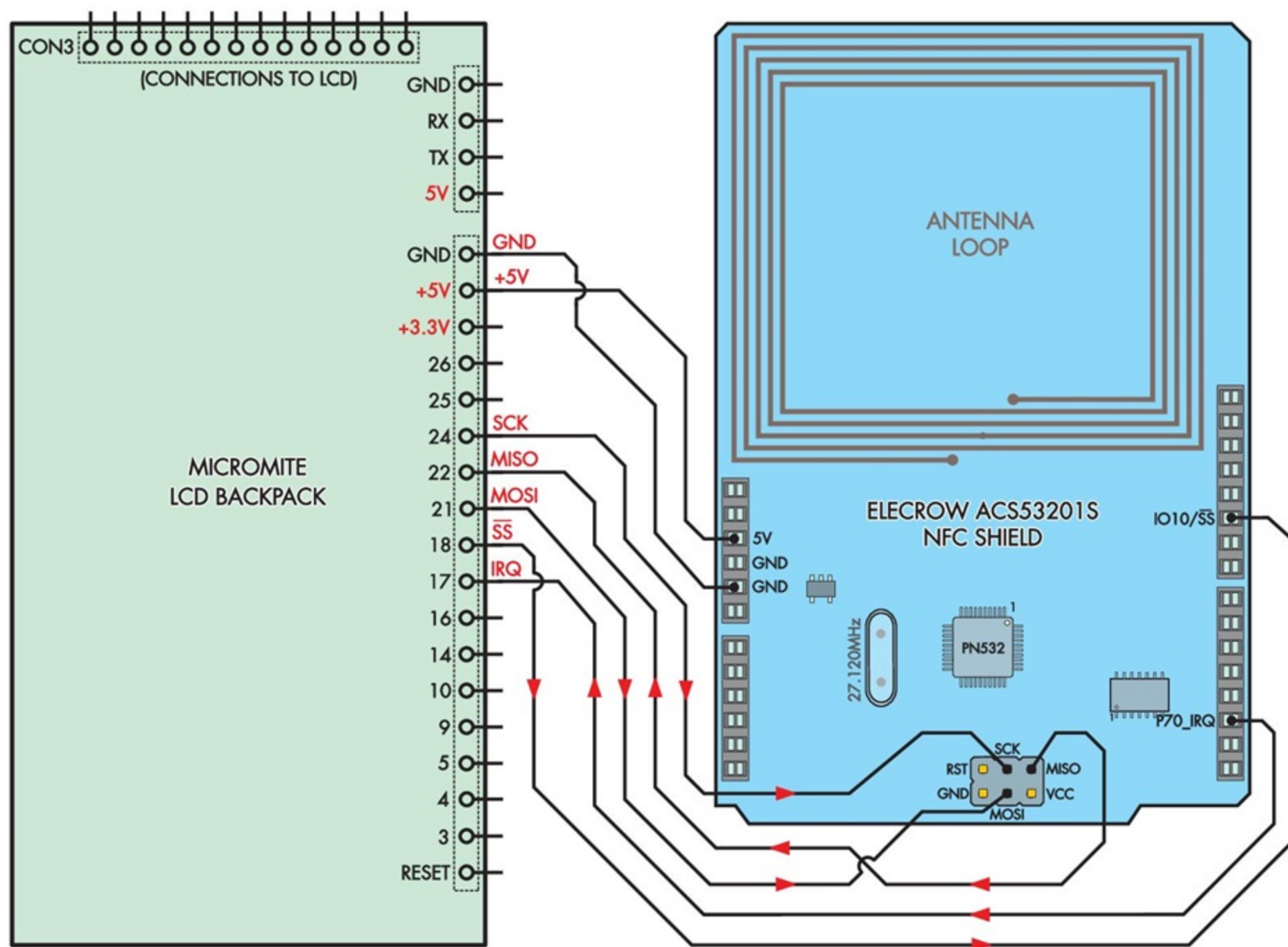
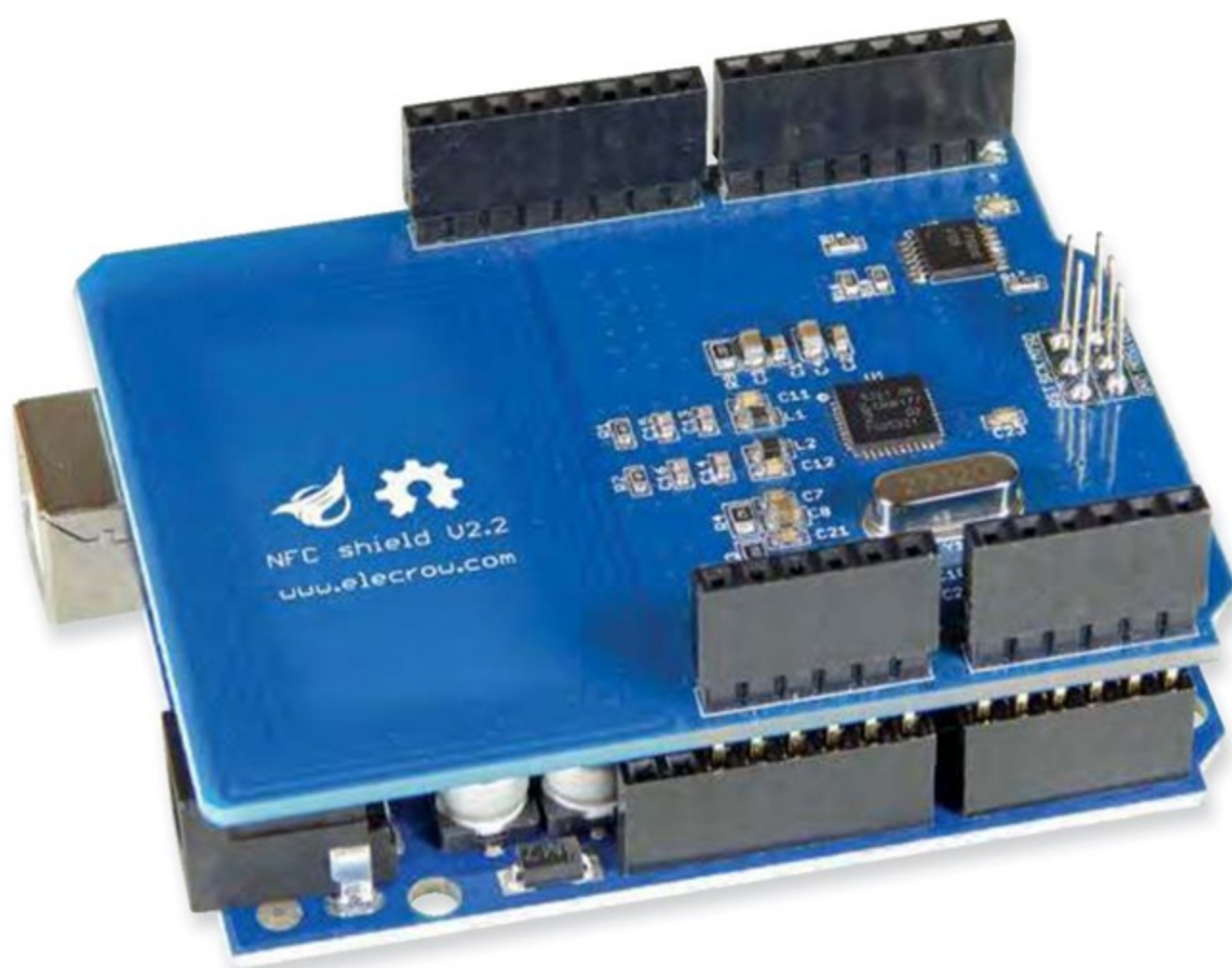


Fig.3: wiring diagram for a Micromite to the Elecrow NFC shield. We've converted the Arduino NFC library into a BASIC library so that you can use it with the Micromite. The library can be downloaded from the *PE* website.

from the September page of the *PE* website. We have also translated some of the example programs. The download package includes several BASIC files which all start with an identical set of library functions, but which have different sample code snippets at the bottom.

Having wired up the shield as in Fig.3, it's simply necessary to upload one of these programs to the Micromite and run it. You should see similar output on the Micromite serial console, as shown in the screen grabs above.



Screen 2 shows the **readAllMemoryBlocks** sketch results when it is used to interrogate the card after using the **writeMifareMemory** sketch to write 16 bytes into the card's memory (to block 8).

The easiest way to build your own application using the Elecrow ACS53201S NFC shield would be to modify one of the example sketches. Or if you're doing something fairly complex (eg, which involves both reading and writing data), you may need to incorporate bits and pieces of the example sketches into your own sketch.

If you want to fully understand how to use the PN532_SPI library functions, it is simply a matter of studying the example sketches to see how they operate.

Using it with a Micromite

What if you want to use the shield with another MCU, like a Micromite? Since it has a standard SPI port, it's quite easy to make the required connections, as shown in Fig.3.

The software is a bit more tricky though since there was no Micromite library available to interface with the PN532 IC. So, we have translated the Arduino library into a Micromite BASIC file and have made this available for download

Extra links

NFC Forum: <https://nfc-forum.org/>

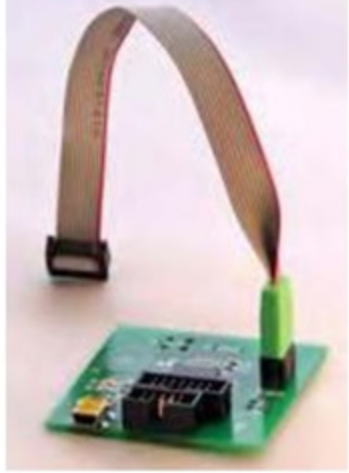
PN532 data sheet: <http://bit.ly/pe-sep19-nfc1>

PN532 user manual: <http://bit.ly/pe-sep19-nfc2>

How to use the PN532: <http://bit.ly/pe-sep19-nfc3>

Elecrow shield library: <http://bit.ly/pe-sep19-nfc4>




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SFX Super Digital Sound Effects Module

Part 2: construction and set-up

You will be amazed by what this tiny powerhouse can do. Whatever sound effect you need, of whatever length, for whatever purpose, this little beauty will do it. And it's even got an audio amplifier on board! Now it's time to put it together and get it to do some real work.

By Tim Blythman and Nicholas Vinen

This new Super Digital Sound Effects Module (*SDSEM*) is tiny and not particularly complex. But, it is very flexible and capable, thanks to its smart software.

We described the circuit and some of the software features last month. However, even since then, we've made some refinements – see the panel opposite.

Now let's get into assembling the module. We'll also describe how to test it, configure the software and put it to use.

Board design

We've made the *SDSEM* very compact so that it can fit just about anywhere. We've also given it flexible supply options. And while it is tiny, we've avoided using any parts which make assembly too difficult.

The most difficult compromise we've had to make is with the micro. We needed one with more than 20 pins to provide all the required functions, as well as enough computing power for all the input/output tasks while mixing digital audio data in real time.

Since we also wanted a very low standby power consumption, that left us with few options.

That meant the only suitable package for microcontroller IC1 was the 28-pin Small Shrink Outline SMD package (SSOP). But don't let the closely spaced pins put you off, because with the right tools it is not difficult to solder. Most of the other components have much larger pins, so once you've fitted IC1 to the board you should find the rest of the construction process quite straightforward.

We highly recommend that you have a magnifying lamp on hand, some precision tweezers and a temperature-controlled soldering iron (ideally with at least one fine and one medium tip). You will also want some good quality flux paste and desoldering braid in addition to your usual tools.

As shown in the parts list published last month, most of the passive components are in 2012 (metric) or 0805 (imperial) packages which have a 2.0 x 1.2mm footprint. These are slightly smaller than components in 3216/1206 packages, which are also quite common.

We find they are not really any more difficult to solder, while saving quite a bit of space on the board. So they are the obvious choice for this project.

Because many of the components (especially the capacitors) don't have any visible markings, it pays to work with one value at a time.

Construction

While today's PCBs are of a very high standard, it is always a good idea to check for shorted or broken tracks before fitting any components. Check carefully where IC1 will sit, as this is where the finest pitch pins are located. Having said that, the chances of finding a problem on the boards we supply is very low.

As we go through the assembly, we'll mention component orientations with respect to the board having the microSD card socket on the left, as shown in the main overlay diagram, Fig.3. Since most of the components are small, we suggest that you set the

temperature of your soldering iron a little lower than you would for soldering larger, through-hole components.

Fig.3 shows the position of all the components on the top of the board, but note that you should fit only one of LK1 or LK2, not both. There are a few components on the bottom side and their locations are shown in Fig.4. You should fit these last, otherwise the board will not sit flat on your bench.

If you are planning to use a 5.5-18V DC supply, you can leave off some components, as shown in Fig.5. For a 3V DC supply only, fit the components shown in Fig.6.

Note though that if you need to be able to change the supply arrangement later, it will be easier to fit all the components now, except for one of LK1/LK2 (as shown in Fig.3). The kit of parts that we supply comes with all these parts; the only real advantage of leaving some off is that you save a bit of time – see below.

Fine-pitch ICs first

Start by soldering IC1 first since it has the closest pin spacings. It comes in an SSOP-28 package, which has pin 1 marked by a small circular dot on the top surface. With the microSD card slot to the left, pin 1 goes to the bottom right and this is indicated by a white dot on the PCB.

Apply some flux to the pads on the PCB and place IC1 in position as closely as possible. Hold it in place by gently

Components – a kit of parts is available for this project. For full details, just visit: www.siliconchip.com.au/Shop/20/4658

pushing down on it and carefully tack one of the corner pins in place.

Some constructors like to use a wooden (spring) clothes peg to hold the IC in position while soldering – as well as giving you back a hand, it precludes that awful smell of burning fingers.

At this stage, it doesn't matter too much if you bridge some of the pins together, as it's possible to remove the bridges with solder braid later.

If IC1 is sitting flat and all the pins line up correctly with their pads, tack down the pins on the other corners to lock it in place. If it is not correct, apply the iron to the first solder joint and nudge IC into the correct location. It may take a few tries before it's perfectly aligned. Try to avoid spreading the solder too much to adjacent pins during this process.

Once you are happy with the location, solder all the pins to their pads. If you have applied flux, then all you should need to do is load some solder onto the tip of the iron and touch it to the ends of the pins where they contact the board.

This will draw a small amount of solder from the iron, using the minimum necessary to make the joint. Keep the tip of the iron clean, and add a small amount of solder directly to the iron each time it runs low.

Now use a magnifying lamp to check thoroughly for any bridges. These can be removed by applying some flux to the top of the affected pins and then pressing some clean solder braid to the pins with the iron. Repeat until all the pins are soldered and not bridged.

We also found it helpful to use a smartphone (a digital camera will do a similar job) to take a close-up photograph. If you do this, you may not have to strain your eyes as much, especially if you look at the photos on a large screen.

When you are happy with the soldering job you've done for IC1, move on to the microSD card socket and

Some revisions since last month

Inevitably, we've made some tweaks to the software since writing the article last month, in order to simplify it. That's what happens with software; it is always capable of being refined.

The first change is to the pin used for varying the playback speed (pitch). Rather than using separate pins depending on whether you are using an analogue voltage or pulse rate to control playback speed, we found a way to combine both of those functions into pin 10 of IC1, which is connected to pin 5 of CON4 (the SW4 input). So now there is a single configuration setting for the playback speed control function.

This was achieved by using the audio output interrupt service routine (ISR) to count pulses, rather than using the hardware pulse counter (TIMER3). Since this ISR runs 46875 times per second to feed the DAC, by checking the pin 5 state in this routine, pulse rates up to 23kHz can be measured, assuming a 50% duty cycle (or 4.7kHz with a 10% duty cycle).

We've also made it possible for this pin to control playback volume as well as speed. Any input can have its speed or volume (or both) controlled by the signal at the SW4 input.

For example, with a model train, you could use read the locomotive's motor voltage (via a suitable divider) as a proxy for speed and use that to control the engine sound. At low motor voltages, the volume and pitch will be low and will steadily increase from a low rumble to a loud roar, giving the impression of having higher RPM and working harder as the motor speeds up.

Alternatively, a potentiometer or variable resistor can be connected to this pin and used as a simple hardware volume control.

The SW4 input can also be set up so that an increasing analogue voltage can be mapped to a decreasing volume or speed. This is set for each input individually, so effects like cross-fades, where one sound increases in volume as another decreases are possible.

The configuration section explains all these settings and how the input signal controls the output sound.

REG1. Their pins are not as closely spaced as those of IC1, but other nearby components will make it more difficult to solder them later.

The microSD card socket should be a bit easier to align than IC1 as it has plastic pins which go into holes on the PCB to help locate it.

Apply some flux to each pad before dropping it into position. Holding it in place, tack down one of the larger tabs on the shell to ensure it stays there.

Once it is flat and you are sure that it is correctly aligned and located, solder all the larger tabs to hold it in place. Now, in a similar fashion to IC1, apply a small amount of solder to the iron, then carefully touch the iron to each pin to solder them to the PCB.

You can use the same technique as for IC1 to remove any accidental bridges. Be careful not to bridge any

pins to the shell, as this is connected to ground.

If you are using REG1 then it is fitted next. It also has a dot to indicate pin 1, but since it is so small it is difficult to see. You will probably need to use a magnifying lamp to see it.

Place REG1 in its spot towards the bottom right of the PCB with pin 1 to the top right, near the REG1 marking on the PCB, with the small dot under the R.

As before, tack one pin in place, confirm the other pins are correct, then solder them all and remove any bridges as necessary.

Remaining components

Now we can mount the passives, which are larger and easier to solder. A pair of fine tweezers will be handy here and a small amount of flux on the pads can even help in this case, too. There

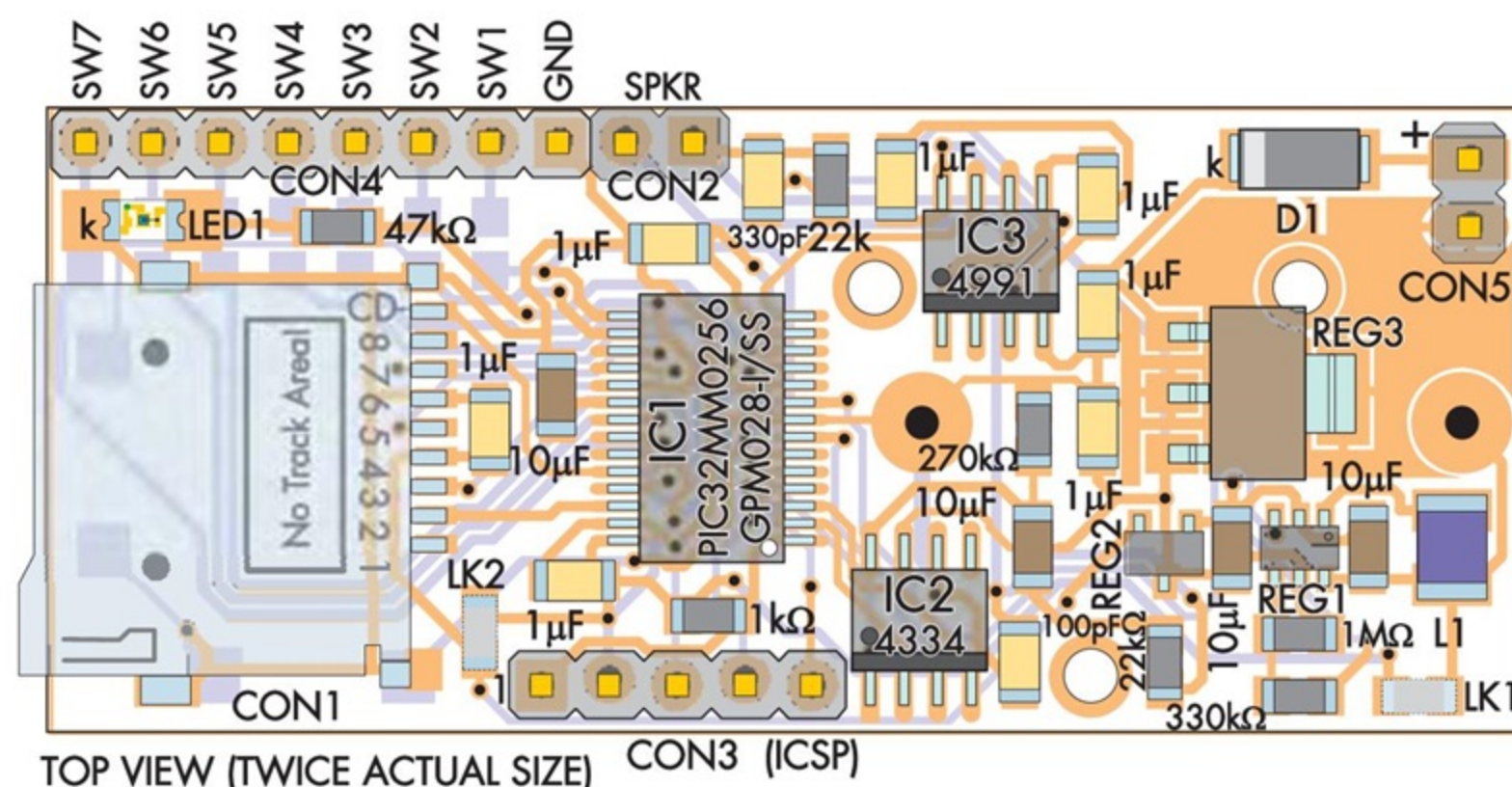


Fig.3 (left): component overlay diagram for the top side of the board, shown at twice actual size for clarity, with a matching 1:1 scale photo above (CON2, 3 and 4 not yet fitted). Do not fit both LK1 and LK2 ; LK1 is for a 3V DC supply, while LK2 (as shown above) is fitted for the 5.5-18V DC option.



Fig.4 (right): underside overlay, shown twice actual size, with 1:1 photo above. Seven $1k\Omega$ resistors are located on this side of the board, along with optional tactile switches S1 and S2, which can be used to trigger the first two sound channels.

are seven resistors and one 0Ω link to mount on the top side of the board.

Refer to the relevant overlay diagram to see which resistors go where. Table.1 shows the codes likely to be printed on the top of each value of each resistor. The 0Ω resistor is for LK1 or LK2, depending on your power supply; fit LK1 if you installed REG1 earlier, otherwise fit LK2.

While it's a bit tricky, it is possible to solder a 2-pin header onto each set of pads for LK1/LK2 so that you can use a jumper shunt to select between the two supply options. But that would only be necessary if you are not sure which one to use in your application.

There are up to thirteen capacitors on the PCB. Be careful not to get these mixed up after you remove them from their packaging as they will not be marked with any values. The only way to identify them if you get them mixed up is with a capacitance meter. Fit these in a similar manner as you did for the resistors, again using the overlay diagram and PCB silkscreen as a guide as to which goes where.

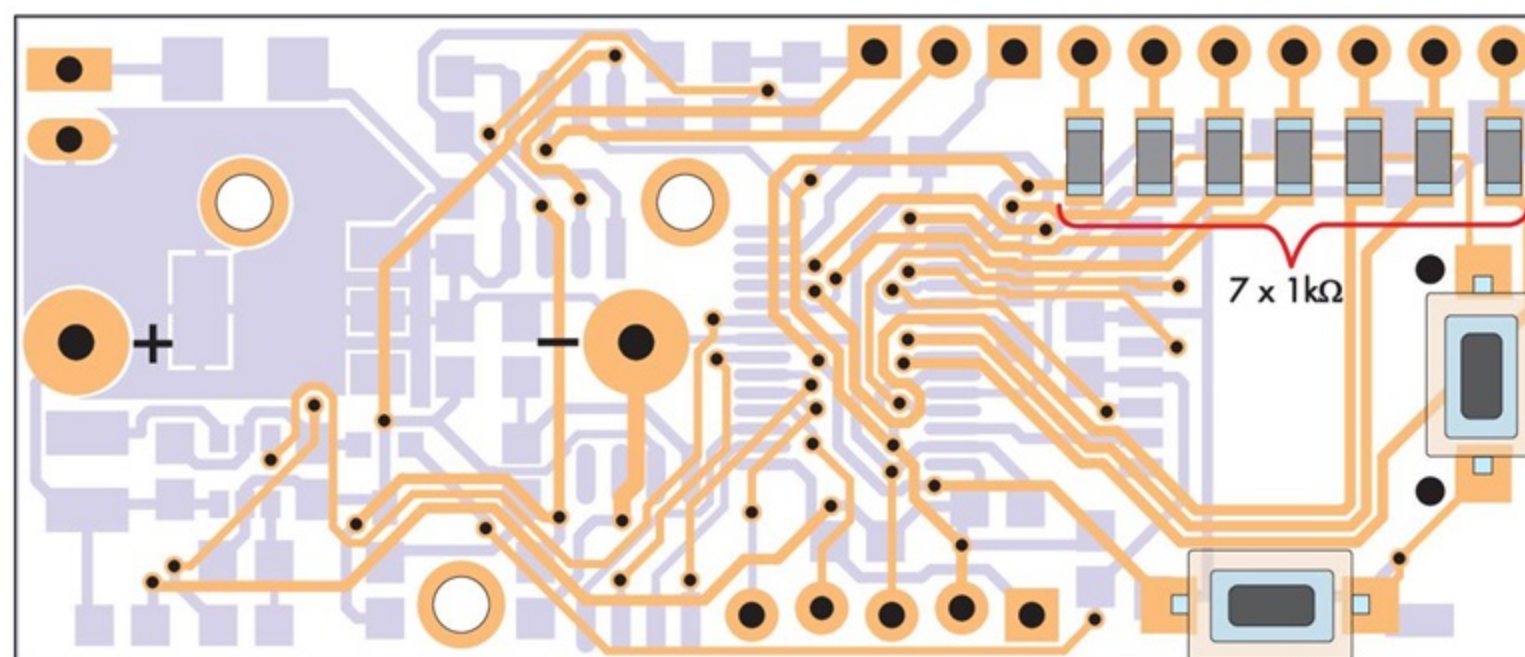
If you fitted REG1 earlier, then solder inductor L1 in place now. Like the resistors and capacitors, it is a 2-lead device, but it is a bit larger. You can solder it in much the same manner but it will probably take a little more heat to form good solder joints.

If you did not fit REG1 then you will need to fit diode D1. This is also a 2-pin device, but it is polarised and must be oriented with the cathode stripe to the left.

LED1 is next; and it goes in the top-left corner of the PCB. It too is polarised and normally it will have a green dot or other marking to indicate its cathode. However, we have seen SMD LEDs with a dot to indicate the anode (ie, the opposite end) so you should use the diode test function of a multimeter to check which end is which.

It will light up with the red multimeter probe to the anode, so the black probe will indicate the cathode.

If it doesn't light up either way around, either you are not making



UNDERSIDE VIEW (TWICE ACTUAL SIZE)

good contact with it or your multimeter is not supplying enough voltage to light it up. Once you have identified its cathode, solder it in place with the cathode facing to the left.

The last components to fit on the top side of the board are regulators REG2 and (if fitted) REG3 and chips IC2 and IC3. Solder them in that order, by tack-soldering one pin first and then checking the placement of the other pins before soldering the rest.

REG2 and REG3 can only be fitted one way but you will need to be careful with the orientations for IC2 and IC3. If fitting REG3, smear some flux paste on its pads first and note that you will need to heat its tab for longer than the other pins to ensure the solder has formed a good joint.

IC2 should have the number 4334 visible on top, while IC3 will be marked 4991. There will be a small depression on the top of IC2 adjacent to its pin 1, which should be oriented so that it is closest to the ICSP header (CON3).

IC3 is soldered near the top of the board, with its pin 1 towards microcontroller IC1, ie, facing the same way as IC2. Now flip the board over and solder the seven $1k\Omega$ resistors onto the pads as marked.

The two tactile pushbuttons, S1 and S2, can now be fitted if you want them.

Additional components

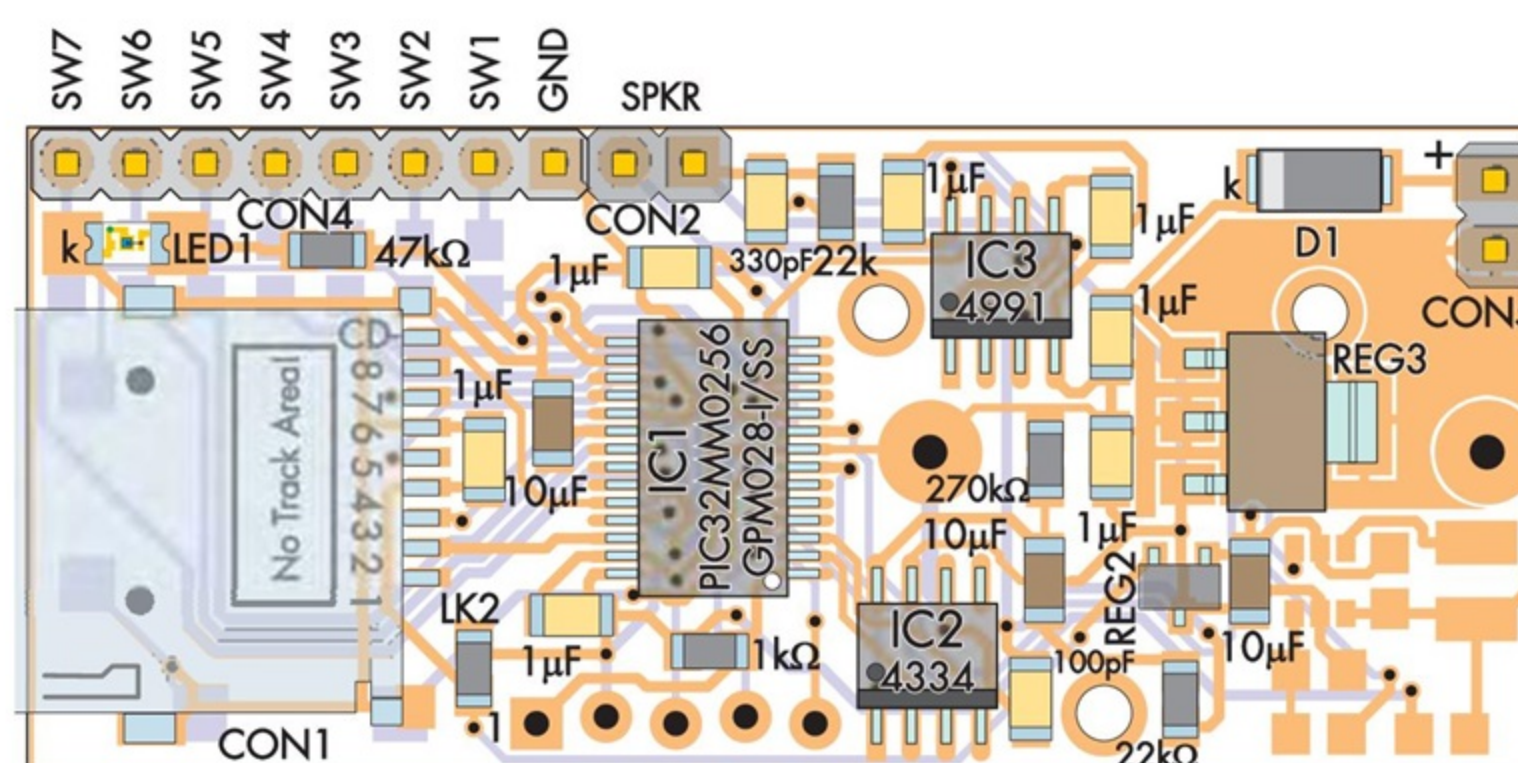
If you want to solder headers for CON2 (the speaker output), CON3 (in-circuit programming for IC1) and CON4 (trigger inputs) then do so now. These can be vertical or right-angle headers and can be soldered on whichever side of the board you prefer. Or you may simply prefer to solder wires directly to the pads on the board instead.

The staggered pins on the ICSP header (CON3) allow you to 'plug in' a header to the board without soldering it. This is useful if you want to program IC1 but don't want a header sticking out of the board when you've finished.

You will need to attach a speaker or piezo transducer to get sound from the module. An 8Ω speaker is recommended if you are using the 5.5-18V input, but is too much of a load on its own for the 3V battery input, as its amplifier output power is very close to the maximum output of the boost regulator. For the 3V battery input, the piezo transducer is the simplest option but an 8Ω speaker in series with a small value resistor (say 100Ω) will reduce the load on the circuit and as a result, it will likely sound better too.

Programming the microcontroller

If you purchase the microcontroller from the *SILICON CHIP Online Shop*,



TOP VIEW (5.5-18V DC SUPPLY) CON3 (ICSP)

Fig.5: this diagram shows which parts you can omit if you only want the 5.5-18V DC supply option. In this case, power is applied via pin header CON5 or supply wires soldered directly to its pads.

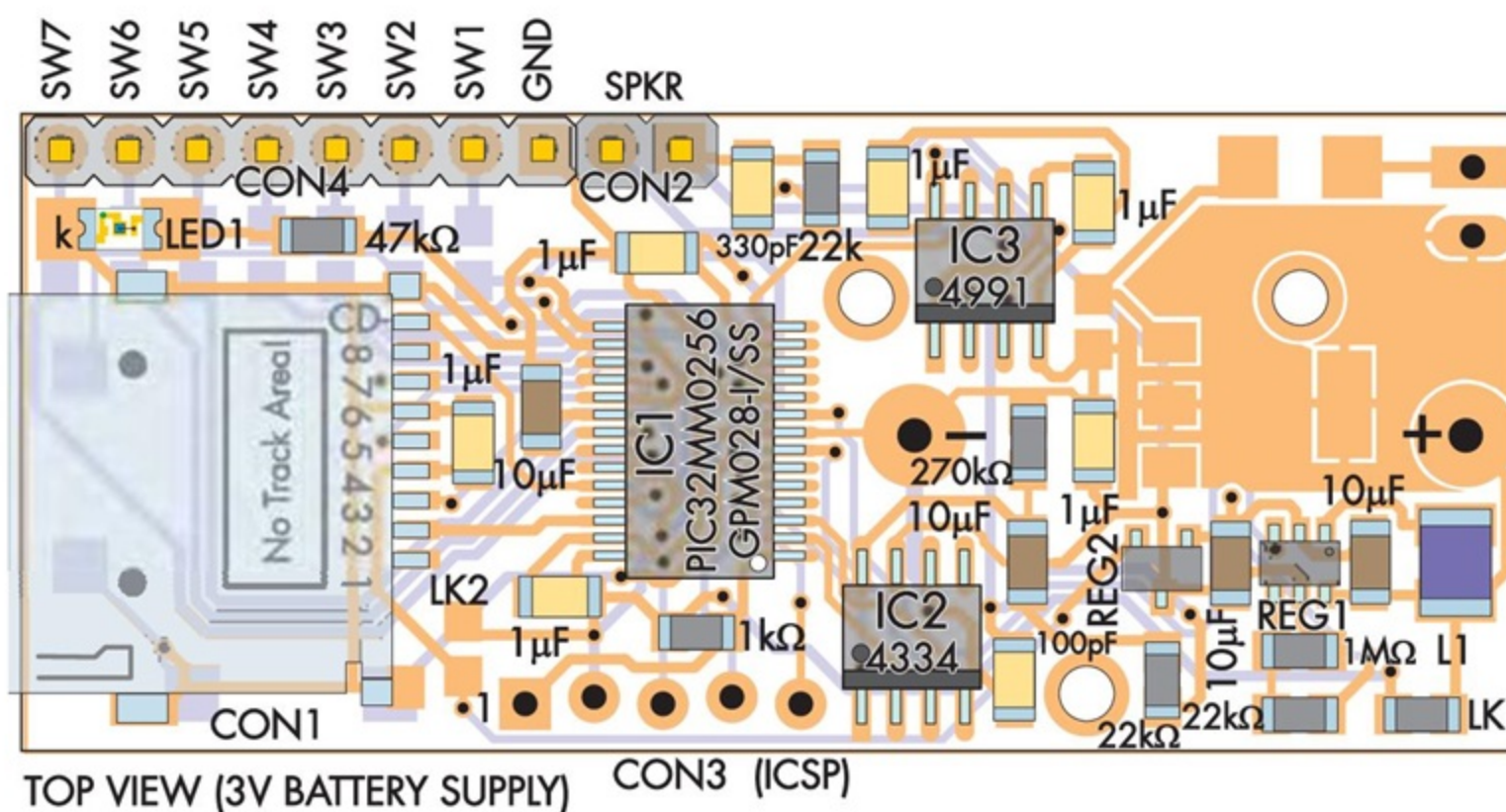


Fig.6: this diagram shows which parts you can omit if you only want the 3V DC battery supply option. In this case, power is applied via wires soldered to the large pads marked '+' and '-' (or pins 2 and 3 on CON3).

either by itself or as part of a kit, it will have already been programmed so you can skip to the *Testing* section below. If we do release an updated version of the firmware later, you could use these instructions to load it into your PIC to take advantage of any improvements.

It's easiest to program the micro once it has already been soldered to the board. You will need an in-circuit serial programmer (ICSP) like the PICkit 3 or new PICkit 4 (see the review in this issue).

Take a standard 5-pin header and push the short end into the staggered holes for CON3. It should be a relatively tight fit and the header won't immediately fall off the board. You don't need to solder the header as friction will make good enough electrical contact to enable programming. However, try to avoid wiggling the header or applying force as it will eventually become loose and will no longer have good electrical contact.

You will need the HEX file which can be downloaded from the August 2019 page on the *PE* website as part of the software package for this project. You will also need a recent version of Microchip MPLAB X installed on your system. It is a free download; you can get it from www.microchip.com/mplab/mplab-x-ide

It includes an integrated development environment (IDE) and an integrated programming environment (IPE). For this task, it is easiest to use the IPE, so when installation is complete, launch that and select your programmer and set the IC type to PIC32MM0256GPM028 (see Screen1). Next, click the Browse button to the right of the Source: field and select the HEX file that you downloaded earlier.

Plug your programmer into CON3 on the board, ensuring that its pin 1 lines up with the pin 1 marker on the board.

You need to apply power to the PIC so that you can program it. You can either do this by connecting the power

SMD Resistor codes

Qty	Value	4-digit code	3-digit code
1	1MΩ	1004	105
1	330kΩ	3303	334
1	270kΩ	2703	274
1	47kΩ	4702	473
2	22kΩ	2202	223
8*	1kΩ	1001	102
1	0Ω	0	0

* 7 are mounted on the underside of the PCB

SMD resistors are marked with a 3-digit or 4-digit code to indicate their value; however, the numbers are pretty small and you may need a magnifying glass or loupe to read them accurately.

supply that you intend using to run the board later, or you can set up the PICkit to supply power to the chip.

To do this, switch the IPE software into Advanced Mode via the Settings menu, 'log on' using the default password, click the Power button at left, enable the 'Power Target Circuit From Tool' checkbox (see Screen2). Having done that, click the 'Operate' button at left to return to the original screen.

You can now program the chip by pressing the 'Program' button. Check the output window below to make sure that programming is successful (see Screen3 below).

If you get an error message, check that there is a good electrical connection between the programmer, header and board, and that pin 1 is in the correct position. Check also that the board is receiving power as expected.

Once the chip has been programmed, the board is ready for testing.

Testing

You will need a power supply that can deliver up to 250mA in short bursts. Refer to Fig.5 and Fig.6 for an overview of where power can be supplied to the PCB.

If you have built the board for the 3V supply option (by fitting REG1) then a battery holder with two AAA cells is a good option. During development, we tested using the 3.3V supply from an Arduino board, two AAA cells and both a PICkit 3 and PICkit 4 to supply power. All four options provided sufficient current for the *SDSEM* to operate adequately.

You may have noticed the footprint for a button cell holder on the back of the PCB. We originally intended this unit to be able to be powered from a lithium button cell, but the cells we tested could not provide enough current. Hence, our recommendation that you use AA or AAA cells.

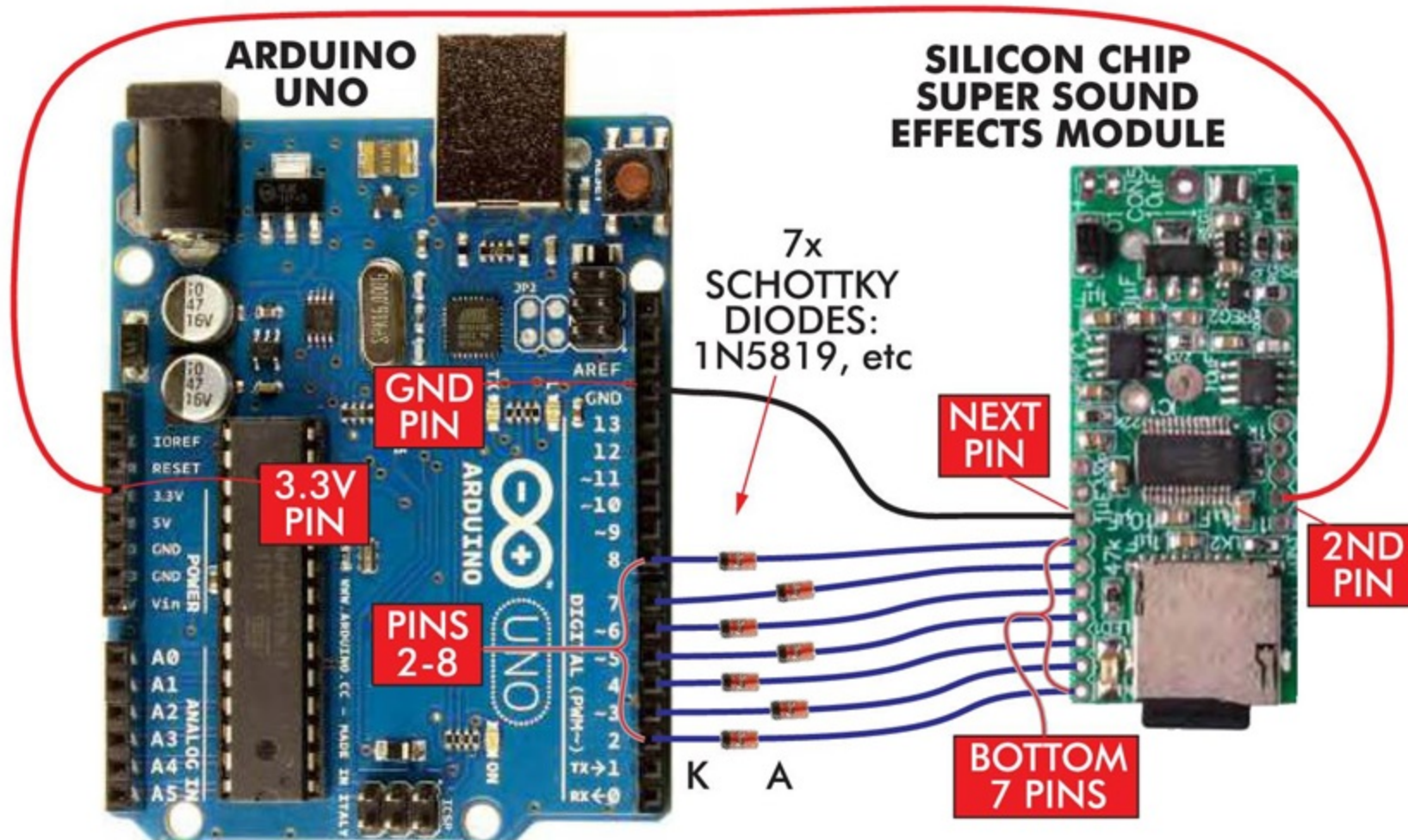
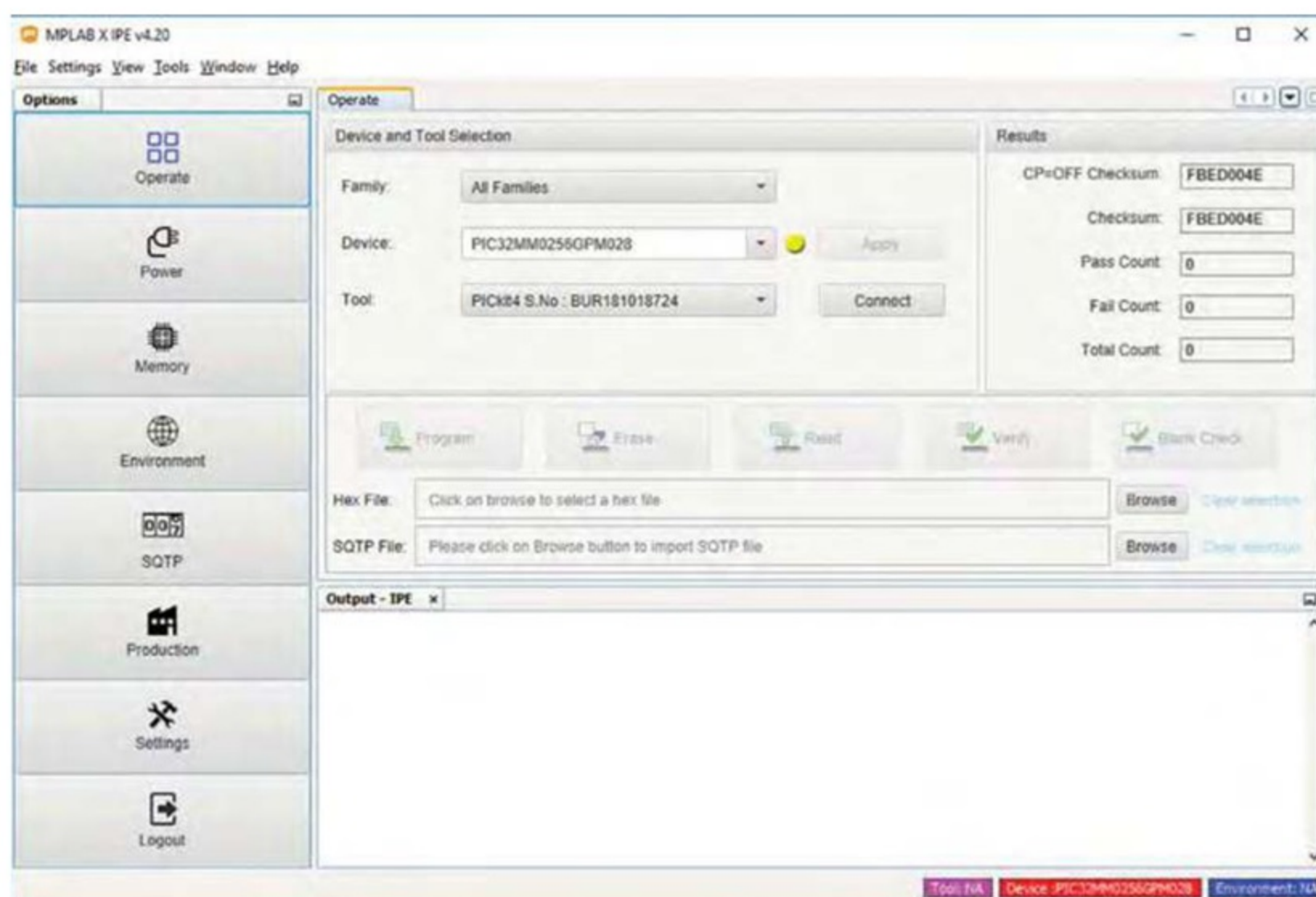


Fig.7: this is one way to drive the SDSEM from an Arduino Uno. The red wire provides 3V power from the Uno (the black wire is the ground connection). The seven schottky diodes protect the 3V inputs on the SDSEM from the 5V outputs of the Arduino.



Screen1: the MPLAB X IPE programming software is a free download and can be used with a PICKit to load the firmware (HEX) file into the PIC microcontroller.

When the unit is powered up without a microSD card present, it starts in a mode which allows you to trigger the built-in samples. So the simplest test is to connect up a speaker or piezo transducer, apply power and then short pins 1 and 8 of CON4, pulling the SW7 input low. Note that these pins are at opposite ends of the header. You should hear the word 'zero' being played back on the speaker.

If you do hear 'zero' then that suggests it's all working normally and you can proceed to test with a microSD card, as explained below. But if you don't hear that word then you will need to check that the supply voltages on the board are correct and that there are no construction errors such as bad

solder joints or swapped or incorrectly oriented components.

Voltage checks

If using the 3V supply option, you have about two minutes between applying power to the unit and REG1 being shut down when IC1 goes into sleep mode. So make sure to do your checks within this time-frame.

First, check the 5V rail voltage. You can measure this between pins 4 and 8 of IC3 (which are in opposite corners) and you should get a reading in the range of 4.9-5.1V. If you don't, then either REG1 or REG3 is not operating properly (whichever is fitted).

If you have fitted REG3 and are not getting a steady 5V reading (and

assuming the supply has not timed out as noted above), carefully check the soldering on REG3, and also on L1, the nearby 1M Ω and 330k Ω resistors and the two 10 μ F capacitors.

A problem with any of these could prevent REG3 from operating.

Assuming the 5V rail is OK, check the 3.3V rail next. This can be measured on the bottom pad of LK2 (closest to the edge of the board), regardless of whether LK2 has been fitted.

For a negative reference, the tip of the black multimeter probe can be pressed into the tab of REG3 (or the pad for the tab, if it has not been fitted).

You should get a reading between these two pads in the range of 3.25-3.35V. If it's outside this range then something is amiss.

Since you've verified the 5V rail voltage, it's likely to be a problem with REG2 or a short circuit elsewhere.

Remember to check this soon after applying power if running from a battery, as this rail will also be shut down eventually to save power.

Testing with a microSD card

We supply some example WAV files and a configuration file (**CONFIG.TXT**) in the software download package for this project.

Copy those files into the root directory of a microSD card, plug it in and power the unit up.

If LED1 is flashing then you may have a problem with the soldering on the SD card socket or there may be a compatibility problem with the card.

We've tested the unit with a range of cards and it works well with all of them, but it's possible that some cards are not supported. So if you can't get it to work, we suggest you try a different brand/model of card just to eliminate that possibility.

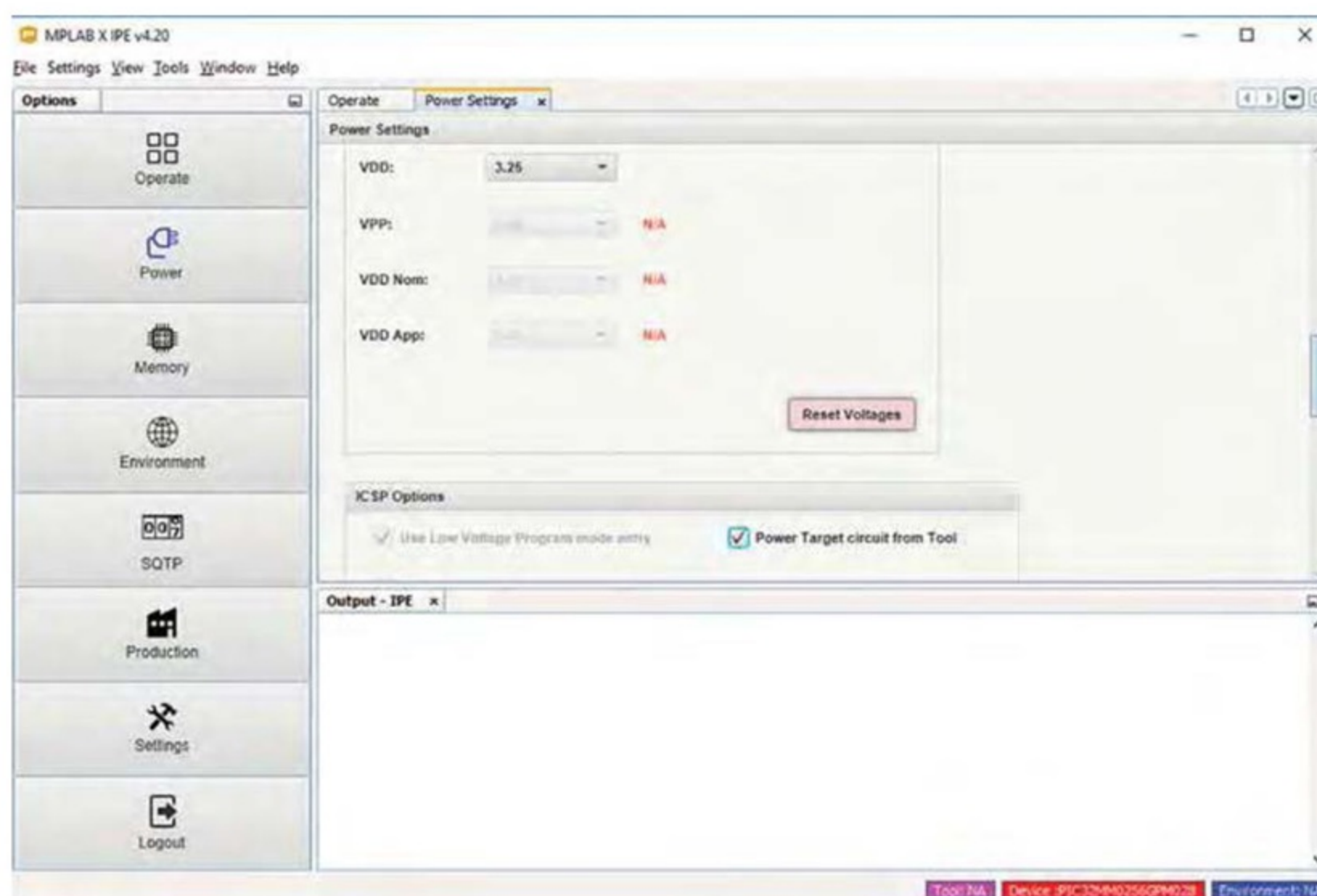
If LED1 is not flashing then you can short pins 1 and 2 of CON4 (or press pushbutton S1 if you've fitted it) and you should hear the first sample being played back. That will confirm that the unit is fully operational.

Configuration file format

The configuration file (**CONFIG.TXT**) is simply a text file consisting of several lines which set the various parameters for the device.

It does not matter what order the settings are listed unless a parameter is repeated, in which case the last instance will override any previous settings given for that particular parameter.

The line starts with the name of the parameter to set, followed by an equals sign (=) and then the value(s). If there is more than one value for a given parameter, they are separated by



Screen2: this advanced options screen in the IPE software allows you to control whether the PICKit will supply power to the micro being programmed via the checkbox near the bottom.

Interfacing with the Super Digital Sound Effects Module

You might be satisfied experimenting with the SDSEM on a breadboard with jumper leads, but if you are looking to incorporate it into another project, you will need to come up with a way to interface to it.

In some cases, you may want to trigger sound effects using something like an Arduino. Keep in mind though that most Arduinos run from a 5V supply while microcontroller IC1 in the SDSEM runs from 3 – 3.3V.

The 1k Ω series resistors on the trigger inputs do allow you to connect them directly without risking damage, but there are some techniques that you can use to make the interfacing a bit smoother.

Since the trigger inputs on the SDSEM have on-board pull-ups, you only need to actively pull those pins low. To set those pins to a high state, the driving device can simply set its output pin to a high impedance and they automatically return to a high level.

So in the case of the Arduino, we can switch the corresponding output pin to a logic low output to activate the trigger and then set it to input mode (instead of driving it to logic high) to release the trigger. Using pin D2 as an example, the Arduino code to set the pin as an active-low output is:

```
digitalWrite(2, LOW);  
pinMode(2, OUTPUT);
```

and the code to set it to a high impedance and allow it to return to a high level is:

```
pinMode(2, INPUT);
```

If for some reason you are using a control device which cannot emulate this type of open-collector/open-drain output, the

alternative is to connect a schottky diode in series with each input, with the anode toward the input. It will be forward biased when the output is low, pulling the input down, but reverse biased with the output high, preventing current from feeding back into the SDSEM (see Fig.7).

You may also want to generate a square wave with a variable frequency to apply to the SW4 input of the SDSEM, to vary the volume or playback rate of certain sounds.

If you are using an Arduino Uno for control, you can easily do this by connecting the SW4 trigger input to digital pin 5 on the Uno. You can then use this line of code to control the frequency:

```
tone(5,300);
```

In this case, it will generate a 300Hz square wave. It would be a good idea to use the schottky diode in this case because the output pin will be actively driven high half the time.

Interfacing with a DCC decoder

We've said that the module is ideal for model railways, and if you are running a DCC system you are probably interested in connecting the SDSEM to a DCC decoder for installation in a locomotive (or even simply connected to the track and hidden in an item of scenery).

If you aren't running DCC, the options are more limited, especially as the track is not powered when the locomotive is stationary.

Since DCC decoders may provide a 12V (or higher) swing from their digital outputs, you should connect schottky diodes in series with each output that goes to the SDSEM, unless you know for sure that those outputs are open-collector types.

commas (,). For example, one line may look like this:

```
switch1=loop,256,dtmf.wav
```

Note that file names cannot contain an equals sign or a comma as this would cause problems parsing the configuration file. Note also that there cannot be spaces before or after the equals sign or commas.

The configuration file is parsed in a non-case-sensitive manner, ie, it doesn't matter whether names are written using lower case letters, upper case or a mixture.

This is also true of how file names are handled; like Windows, they are matched in a case-insensitive manner. So a file called **Train Horn.wav** can be referred to as **train horn.wav** or **TRAIN HORN.WAV** and it will still work.

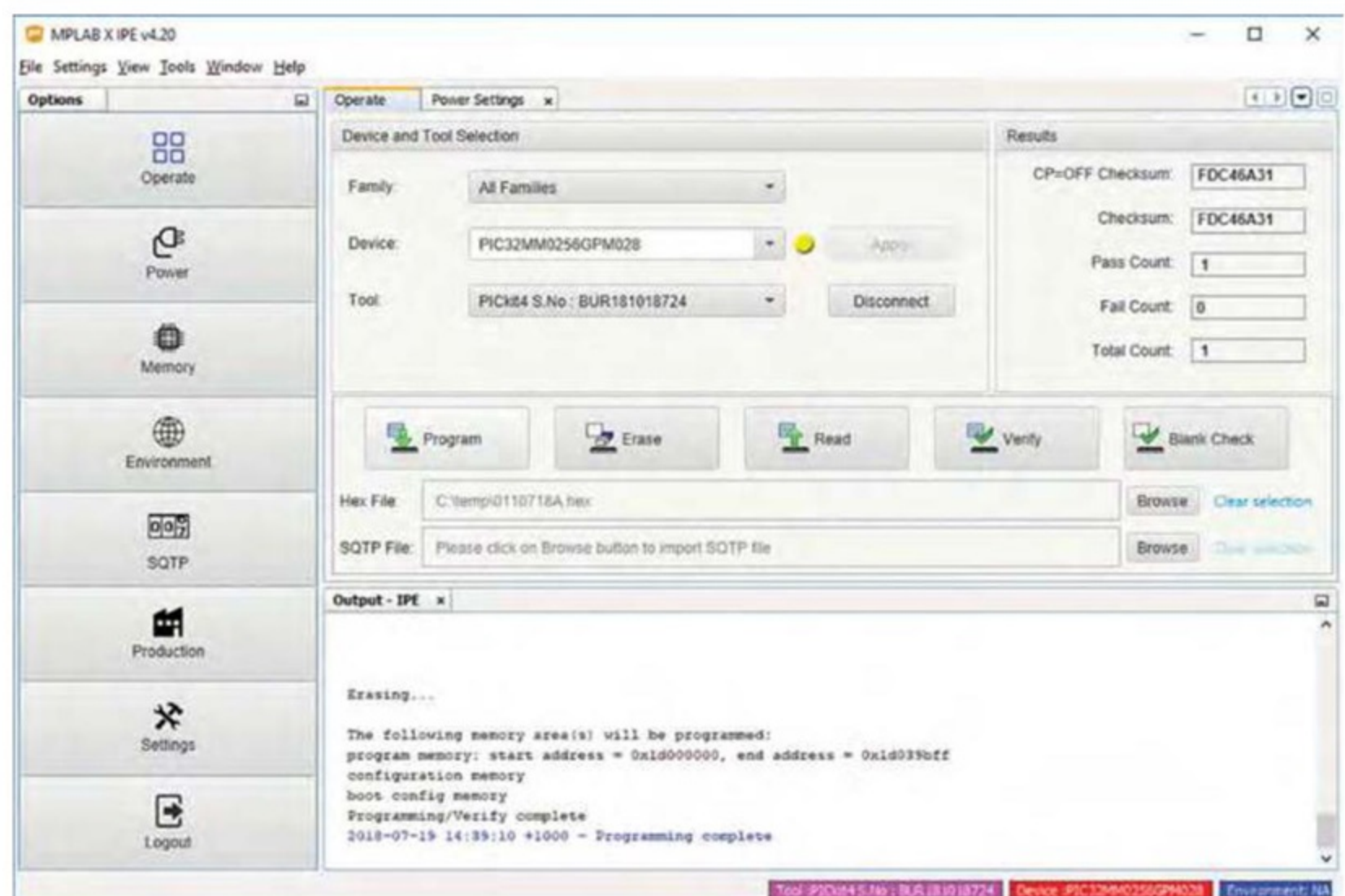
Refer to the panel listing the configuration parameters overleaf for an understanding of what each line does.

If you are familiar with programming or shell scripts, you might be accustomed to placing a hash (#), a double slash (//) or single quote (') at the start of a line to 'comment it out' so that it is ignored.

Any of these characters can be used in the **CONFIG.TXT** file to achieve that effect.

Example of a typical configuration file

```
MASTERVOLUME=128  
LOGIC=LOW  
STANDBY=120  
SWITCH1=ASR,64,256,112,384,DIESEL1.WAV,DIESEL2.WAV,DIESEL3.  
WAV  
SWITCH2=ASR,256,256,256,256,HORN1.WAV,HORN2.WAV,HORN3.WAV  
SWITCH3=LOOP,256,256,256,256,BELL.WAV  
SWITCH5=SINGLE,256,256,256,256,ANNOUNCE.WAV  
SWITCH6=ASR,256,256,256,256,WHISTLE1.WAV,WHISTLE2  
WAV,WHISTLE3.WAV  
SW4MODE=ANALOG,1000,3000  
SPEAKBACK=NONE
```



Screen3: once the PICKIT is plugged in, the HEX file loaded and power applied, click Program and if the operation is successful, you will get a similar output to that shown here.

Configuration parameters

MAINMODE

Currently, the software only has one mode which is called 'mixed' and this refers to the fact that if multiple sounds are triggered, then they will be mixed together before being played back. We suggest that you include the following line in your configuration files to ensure compatibility with future software versions which may add other modes:

"MAINMODE=MIXED"

MASTERVOLUME

This sets the volume for all channels. Its sole parameter is a whole number between 0 and 256. 256 means maximum volume, however, this can lead to clipping and distortion if multiple loud sounds are played simultaneously.

You may need to experiment with this value. A good value to start with is 128 (ie, half maximum volume).

LOGIC

The LOGIC parameter can be set LOW or HIGH, which dictates whether sounds are triggered when an input is pulled low (the default) or high.

The pins have internal pull-ups in either mode, so sounds can be triggered using external switches, relays, transistor collectors or FET drains to pull these pins to ground.

STANDBY

This sets how long the SDSEM will wait after playing the last sound before it goes into low-power sleep. If set to zero, the SDSEM will never go into sleep mode. Use this setting if the power supply cuts out when the module is not in use. The SPEAKBACK function will say 'power standby off' in this case.

The value given is in seconds, up to a maximum of 357 (which is just under six minutes). When it goes into sleep mode, current consumption is around 20µA if running from a 3V battery. If a sound is triggered in this mode, playback will take up to half a second to resume (but typically around 250ms). This is because the SD card needs to be re-initialised each time it is powered up.

So the standby timer provides a compromise – there will be a slight delay between the first trigger event in sleep mode and the sound being played back, but the unit will then remain in idle mode for the specified time so that subsequent trigger events will not incur any delay.

So if you are running the unit off the battery, you will want to have a non-zero sleep mode to avoid draining it too quickly.

On the other hand, if you're running from mains-derived power or if you are cutting the power externally when the unit is not being used (eg, using a physical switch) then you can set the idle period to zero to disable sleep and avoid the delay upon wakeup.

In the case of a non-zero timeout, the speak-back will read back as 'power standby' followed by the number of seconds. In the low-power mode, the amplifier and boost regulator are shut down, which also means that the microSD card will shut down.

SWITCH1 to SWITCH7

The number following 'SWITCH' refers to a trigger input. The parameters dictate what sounds are triggered when that input is activated. There are five control values, followed by between one and ten file names.

The first control value is the playback mode for this input, which also dictates how many sound files can be referenced. This is either LOOP, SINGLE, CROLOOP, CROPSINGLE, ASR, ALTLOOP, ROUNDROBIN or RANDOM. The first four modes require just one file, while ASR takes up to three and ALTLOOP takes two. The last two modes, ROUNDROBIN and RANDOM can use between two and ten files.

If more files are listed than necessary for a given mode then they are ignored. If a file name is left blank then no sound is played in that case.

The second and third control values set the volume for files triggered by this input. The first volume is what we call the low volume and the second one is the high volume. They only need to differ if you are using the variable playback volume feature which requires a control signal to be applied to the SW4 trigger input.

The SW4MODE parameter is used to enable this (see below). If enabled and the low and high volumes are different, then the playback volume for sounds triggered on this input will vary between those two values, based on the signal at the SW4 input.

The fourth and fifth control values are used to vary the playback speed/pitch, with the values being the low sampling rate (#4) and the high sampling rate (#5).

These work in a similar fashion to the volume parameters, and also have a nominal value of 256. So with a value of 256, the playback rate will equal the file's sampling rate, while higher values will play it back faster and lower values slower.

The minimum possible playback rate is 1kHz and the maximum is 65kHz. Generally, you would use files with sampling rates around 8-22kHz, so this gives plenty of scope for adjustment.

It is possible for the low volume to be higher than the high volume, in which case the volume will decrease with an increasing control signal on the SW4 pin. And the same comment applies for the playback rates.

Any subsequent values after these five parameters are interpreted as file names. Files must be stored in the SD card's root directory. They must be in PCM (uncompressed) WAV format, with 8-bit or 16-bit samples and in mono or stereo.

SW4MODE

The first value for this parameter is either TRIGGER, FREQUENCY or ANALOG. If the mode is set to TRIGGER then the SW4 input can be used to trigger sounds like any of the other trigger inputs.

If the mode is set to ANALOG then the voltage on that pin instead controls the volume and/or playback rate of audio samples triggered by other inputs.

Two additional parameters must be provided, and these are the lowest and highest expected voltages (in a whole number of millivolts) on this pin. These correspond to the minimum and maximum volumes and playback rates specified for the affected trigger inputs.

If the mode is set to FREQUENCY then the pulse rate/frequency applied to this pin is used to control the volume and/or playback rate of audio samples triggered by other inputs. Two additional parameters must be provided and these are the lowest and highest expected frequencies (in Hz) on this pin. These correspond to the minimum and maximum volumes and playback rates specified for the affected trigger inputs.

If the voltage/frequency at SW4 is outside of the specified range then the volume or playback rate will be 'pegged' at the minimum or maximum value; ie, if the voltage/frequency is below the minimum voltage then you will get the minimum volume or playback speed and if it's above the maximum then you will get the maximum volume or playback speed.

Within the specified range, the effect is a smooth transition between the limits.

Note that if you are using the ANALOG mode, the software enables an approximately 350µA pull-up current on the SW4 pin. If this pin is driven from a low-impedance voltage source then the pull-up current will be overwhelmed by that source. But this allows you to connect a variable resistor between SW4 and 0V and then control the voltage on this pin by varying the resistance.

For example, a 5kΩ variable resistor will give a voltage of between 0.35V and 2.1V (note that there is already a 1kΩ series protection resistor in the circuit). But the pull-up current value is nominal and the actual voltage range may vary slightly.

In FREQUENCY mode, the maximum frequency is around 23kHz (assuming a 50% duty cycle) and the resolution is about 5Hz.

Again, the pin's internal pull-up is enabled, allowing a transistor collector or MOSFET drain to pull this pin low to control the frequency.

SPEAKBACK

The SPEAKBACK debugging parameter can be set to ALL, SUMMARY or NONE, and defaults to ALL to make troubleshooting easier.

When set to ALL, the values provided for all the above parameters are 'read out' via the audio output when the SDSEM starts up.

This is done by playing back audio samples stored in its internal Flash memory (these samples take up about 95% of the Flash space).

It is not possible to read out the individual file names, so in each case where a file name is encountered, you will either hear 'OK' if the file is present or 'NOT OK' if it has not been found or is too small to be a WAV file.

Note that at this point, the unit has not actually checked the contents of the file, so you may hear 'OK' even if a file is corrupt or is not in the correct format.

When SPEAKBACK is set to SUMMARY, the result is the same as above except that it skips over the settings of the SWITCH1-7 parameters to save time. If set to NONE, no reading out occurs and the unit starts normal operation immediately upon power being applied. So you would normally have a line reading 'SPEAKBACK=NONE' in your configuration file once you are sure the settings are correct.

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WHITE NOISE GENERATOR

This white noise generator is very simple and cheap to build. It produces white noise which does not repeat over any short time frame and has a variety of uses, as explained below.

by John Clarke

A white noise signal has equal intensity at all frequencies in the band of interest; for example, 20Hz-20kHz for audio. It's the hissing sound that you hear if you tune an analogue FM radio to a frequency on which there is no transmission.

There are many reasons why you may want a white noise signal. For example, you can use white noise to drown out external noises that may interfere with your sleep. If that dripping tap is keeping you awake, don't count sheep; try a low-volume white noise source with a speaker close to your bed.

We can attest: it works wonders!

It's especially effective at helping babies get to sleep since they are used to hearing somewhat similar sounds in the womb. It can also be used to help treat (or at least mask) tinnitus (a persistent ringing sound heard in the ears when there is no sound present).

White noise sources can be used to measure the bandwidth or impulse response of a circuit and to check room acoustics or optimise a PA system.

They are also used in analogue audio synthesisers to help produce the 'ssshhhh' sound of various percussion instruments, such as hi-hats, snare drums and cymbals.

Generating white noise

There are several ways to generate white noise. For example, if you reverse-bias a zener diode or transistor emitter-base junction (ie, the base-emitter reversed) with a low DC current level, an AC voltage will appear across it and this will have a white noise characteristic. However, the resulting AC voltage level is quite low

and typically needs to be amplified by a factor of several hundred times to make it usable.

Alternatively, white noise can be generated digitally with a pseudo-random number generator.

This has the advantage that the signal level is already high, it is consistent and it is not dependent on a particular transistor or zener diode's characteristics.

National Semiconductor used to sell a digital noise source IC, the MM5837 (designed in the 1970s) that used an internal 17-bit pseudo-random sequence generator to produce white noise for audio applications. Supplied in an 8-pin DIL package, it was designed for musical instruments, synthesisers and for room acoustics testing.

Its main disadvantage was a noticeable cyclic repetition. The repetition was due to the full random sequence being produced in less than one second and being continuously cycled.

This IC is not available any more, but with modern components, we can make an even better digital noise source.

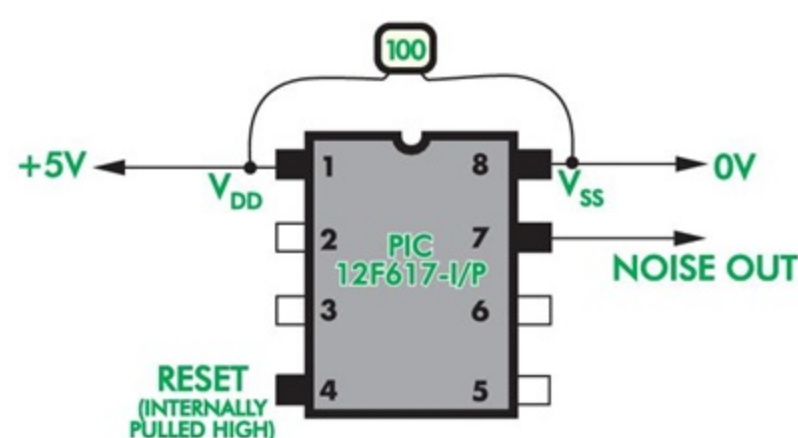


Fig.1: the 'circuit' could hardly be simpler – everything is done in software in the PIC12F617-I/P. Noise output is taken from pin 7, while a 100nF capacitor bypasses the supply (pins 1 and 8) – pins 2, 3, 5 and 6 are not connected.

An improved white noise source

Our design uses a low-cost 8-bit PIC12 microcontroller to produce a 31-bit pseudo-random sequence, which only repeats after 2^{31} or approximately two billion cycles. That works out to nearly eight hours, so the repetition is definitely not discernible.

The basic 'circuit' for our white noise generator is shown in Fig.1. IC1 is a PIC12F617-I/P, which has a 2-5V supply fed into pins 1 and 8. A 100nF bypass capacitor is connected directly between pins 1 and 8 to ensure that it has a stable operating voltage. The noise output appears at its GP0 digital output (pin 7).

Pin 4 is the master clear/reset (MCLR) pin. This is held at V_{DD} during normal operation by an internal pull-up current. If it is externally pulled low, this will hold the microcontroller in a reset state and so the noise output at pin 7 will cease. When released, the internal pull-up will bring it high again, allowing the processor to run and resuming noise generation.

You just need the two components, the programmed IC and a 100nF bypass capacitor, as shown in Fig.1.

And it's dead easy to wire up since only four pins are normally used – the bypass capacitor can be soldered right next to the IC (even right across pins 1 and 8 if you wish!). The other four pins (pins 2, 3, 5 and 6) are not used and should be left disconnected.

Pseudo-random sequence generation

Fig.2 shows how the software generates a pseudo-random sequence generator using three 8-bit shift registers and a 7-bit shift register. The bits within

the four shift registers are labelled Q1 to Q31. The software is available for download from the September 2019 page on the *PE* website.

These bits are pre-loaded with a specific value when the micro comes out of reset, to provide a starting point for the random sequence; as explained below, this can be any state but all zeros.

Each time a clock pulse occurs, the value of Q1 is moved into Q2, Q2 into Q3 and so on, up to Q30 which is moved into Q31. This means that all the bit values are updated from their neighbour, except for Q1. It gets its value instead from the output of a two-input exclusive-OR (XOR) gate, with its inputs being the values of bits Q28 and Q31.

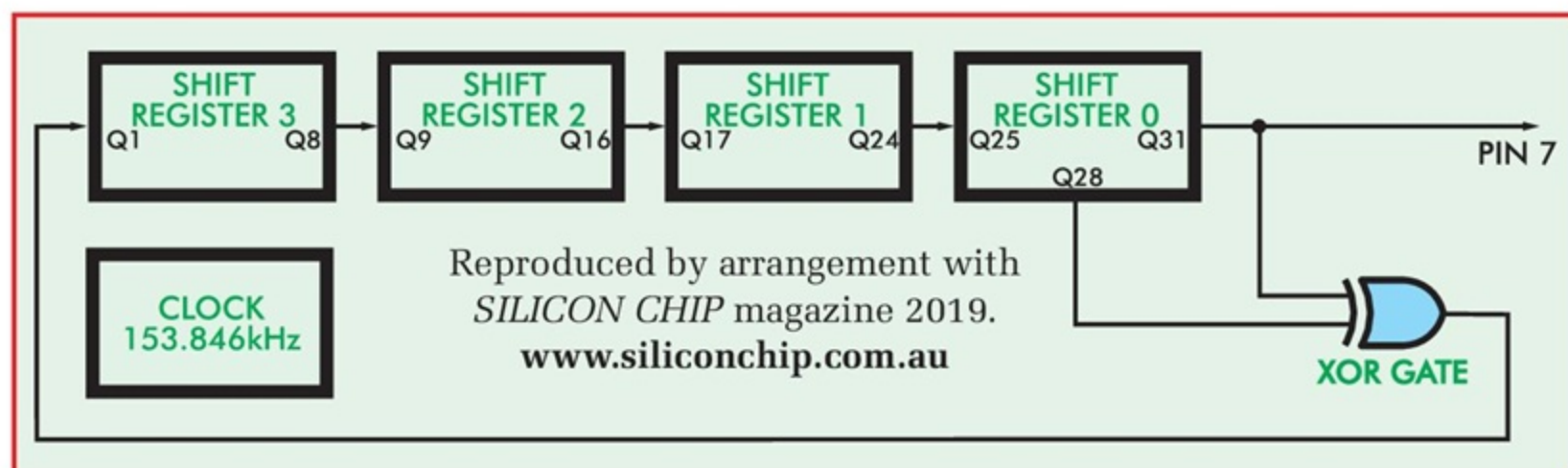


Fig.2: here's what happens inside the PIC – the 28th and 31st bits are XOR-ed and fed back into the first bit, while the other 31 are shifted to the right by one.

and this results in a sampling rate of 153.846kHz ($2\text{MHz} \div 13$). When divided into the cycle length, this gives us the approximately eight-hour repeat rate mentioned earlier. The noise frequency distribution is therefore even up to about

it is something that we will cover in a future article.

Pink noise has its own uses, such as for calibrating audio equipment, simulating background noise and it can also help with sleeping.

Ensuring a long repetition time

You may be wondering how we know that the sequence generated by this arrangement won't repeat for 2^{31} cycles.

That is guaranteed by using the correct 'taps' (in this case, bits 28 and 31) to be combined to generate the new value of Q1 for each cycle.

The list of taps required for various length shift registers to ensure a maximum length repeat cycle is given on page 5 of the following application note: <http://bit.ly/pe-sep19-wng>

Note that this document refers to the use of an XNOR (exclusive NOR) gate rather than XOR gate. The only difference is with the lock-up state. That is the initial state of the shift registers where the generator stops producing a varying output.

The XNOR version has a lock-up state when all values in the shift registers are ones (high output), whereas the XOR has a lock-up state of all zeroes (all low).

The lock-up situation is prevented from happening when using either XOR or XNOR gates by starting the noise sequence with a number other than all zeroes or all ones.

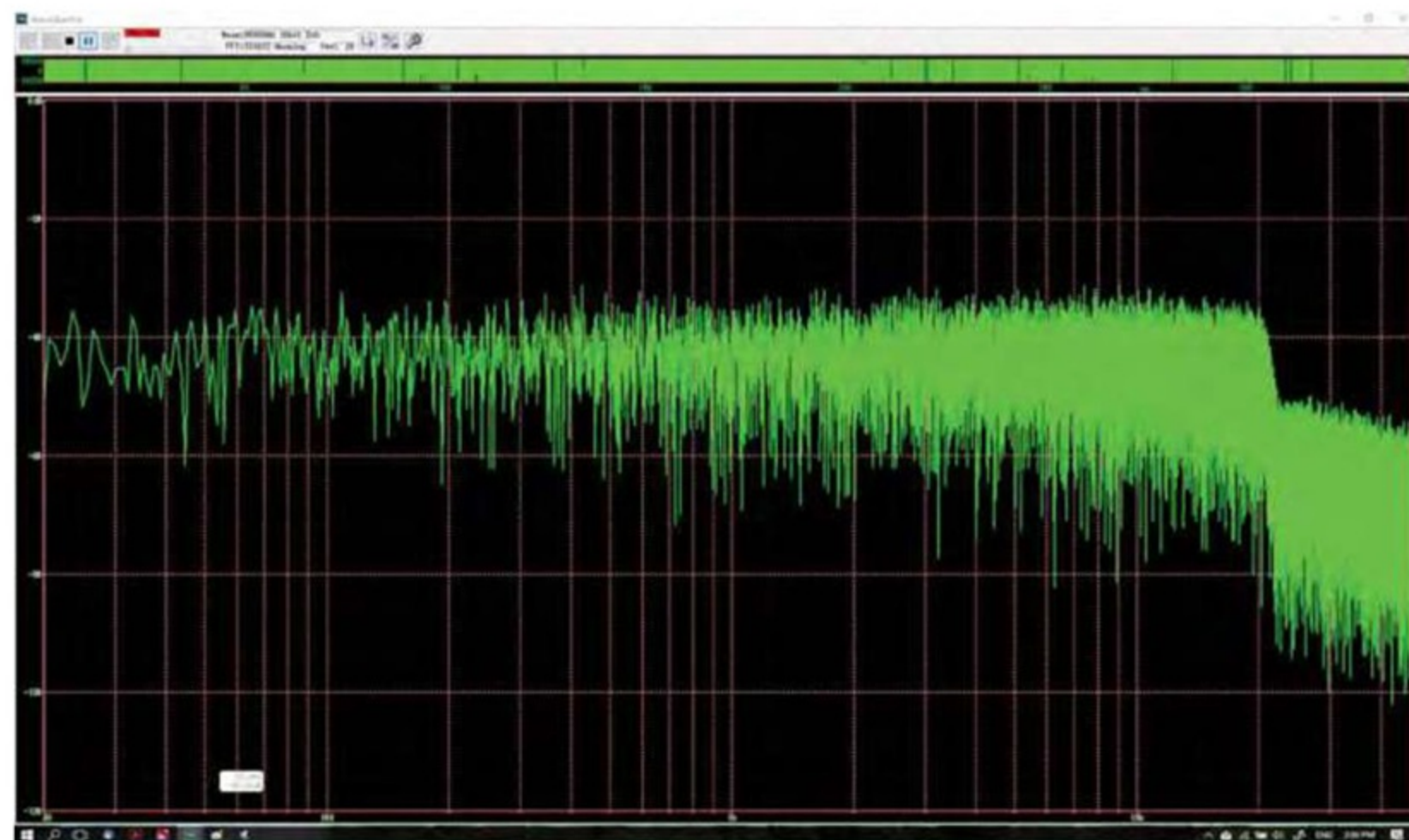


Fig.3: the spectrum of the white noise generated by the PIC. The power level is consistent across all frequencies up to about 20kHz. The drop in level discontinuity at 20kHz is due to sound card and computer software limitations.

Once this shifting is complete, the value of Q31 is effectively lost, although it does control the value loaded into Q1, so you can think of this as a modified type of 'bit rotate' operation.

The Q31 bit value also determines the level on pin 7 and thus becomes the noise output; hence we do not want to retain its value in one of the other bits; if we did, this would quickly lead to repetition.

This approach has two advantages. One, the 31-bit length leads to a very long time until the sequence repeats and two, the simple XOR gate used to provide the pseudo-random effect is very easy to implement in software and takes very little time to process, allowing for a high clock rate and thus giving the noise signal a wide bandwidth.

The entire process to update the contents of the four registers, including the XOR operation, takes 13 software instructions.

The PIC12's internal 8MHz oscillator gives a 2MHz instruction rate (it takes four cycles to execute one instruction)

76.923kHz, which is the Nyquist limit for this signal; ie, half the sampling rate.

Because the output is a square wave, it will have components at higher frequencies than this, but they will have a decreased amplitude and power level.

The measured spectrum from our prototype is shown in Fig.3. It extends over the entire audio spectrum (20Hz-20kHz) and well beyond at both the low-frequency and high-frequency ends (the measurement bandwidth is only 20kHz).

While the IC generates white noise, it could potentially be used to generate pink noise with an appropriate filter at its output. But such a filter is not simple to design;



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Circuit Surgery

Regular clinic by Ian Bell

Understanding bipolar junction transistors – Part 3

This month, we continue with our look at the different bipolar transistor circuit configurations – common emitter, common base and common collector – inspired by a question on this topic on the EEWeb forum. In July's first article in this series we introduced the concept of transistor configurations, the basic operation of the transistor and the equivalent circuit models that are used to analyse circuits. Then, last month (August) we looked in detail at the most widely used configuration – the common-emitter amplifier, also going into more depth on bias and the use of models to analyse the circuits that are relevant to working with all the configurations. This month, we will look at the common-base amplifier and also, because it relevant to understanding the differences between the configurations, we will discuss input impedance and the operation of the circuits at high frequency.

Common base

Looking at the different configurations in Fig.1 we see that in both common-emitter and common-base configurations the output is from the collector. As with the common-emitter circuit discussed last month, to use this configuration we add a resistor between the collector and the power supply. This provides a route for power to get to the transistor so that it can act as an amplifier, and it converts the varying collector current (transistor output current signal) into a varying collector voltage. Thus, we get the circuit in Fig.2, but exactly as we discussed for the common-emitter circuit, this circuit is not practical because we also need to provide bias.

Following on from the discussion on bias and operating point last month, we can apply much of what we looked at then to

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*. The examples and files are available for download from the *PE* website.

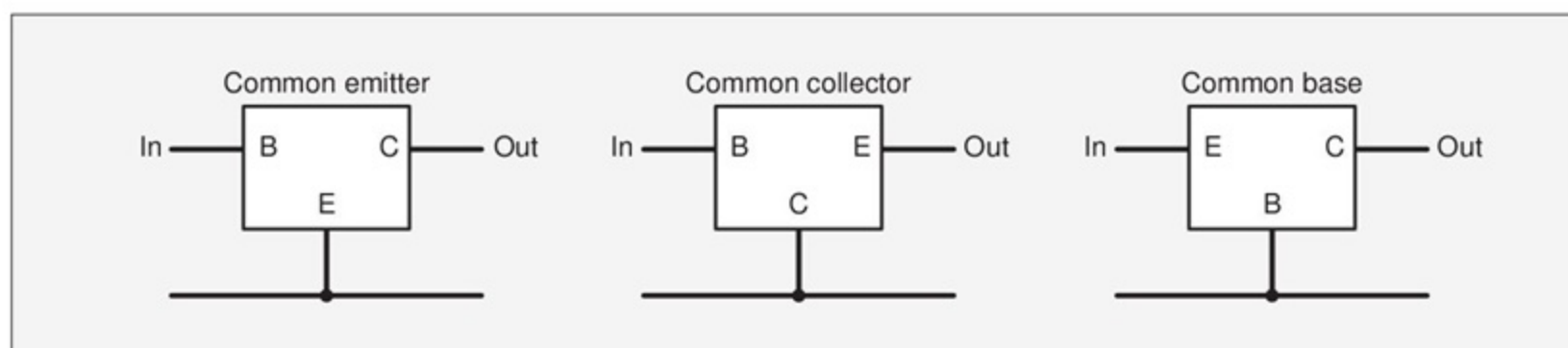


Fig.1. Concept of transistor configurations. These apply to both NPN and PNP. Actual circuits require additional components.

the common-base circuit. In both cases we need to set the operating point of the transistor by forward biasing the base-emitter junction with a DC voltage that will cause the no-signal collector current to be set to the level we require. As with the common-emitter circuit, the base-emitter bias voltage for common base can be set using a potential divider connected across the supplies. Fig.3 shows the biasing circuit for the common-base amplifier, in which R1 and R2 form a potential divider setting the voltage on the base.

Bias

Last month, we discussed bias stability and the use of feedback to deal with the high sensitivity of the bias to variations in transistor characteristics – variations both between individual devices and with changes in temperature for a given transistor. This was achieved by putting a resistor between emitter and ground. R4 plays the same role in the circuit in Fig.3. In fact, the configuration of resistors in this circuit is exactly the same as for the common-emitter amplifier, but the circuit is drawn with a different layout to emphasise the use of the emitter as the input.

The bias resistors values can be set

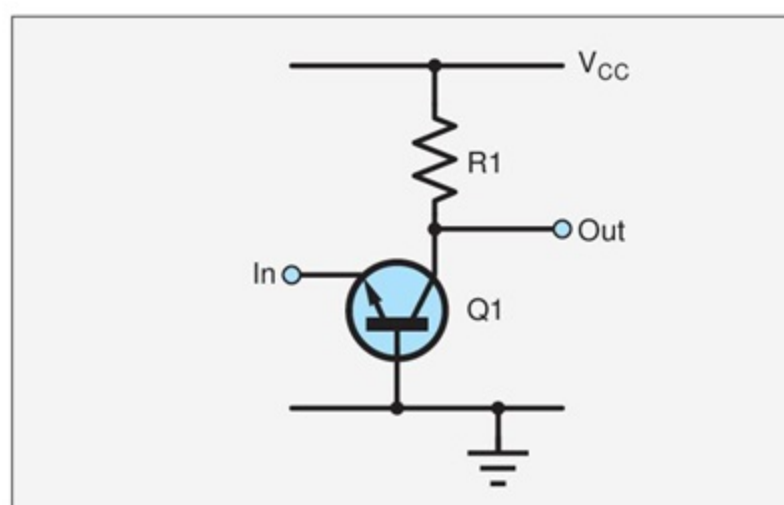


Fig.2. Basic common-base amplifier without bias circuitry.

in a similar way to the common-emitter amplifier. Choose the operating collector current (I_C) and voltage at the emitter (V_E) with no signal; typically, this is in range of a tenth to a third of the supply. This voltage and current set the value for R4 ($= V_E/I_C$). The operating current and R3 set the no-signal voltage at the collector; this is $V_{CC} - R_3 I_C$. Often, this voltage will be in the range of half to two thirds of the supply. The voltage drop across R_3 ($= R_3 I_C$) sets the maximum amplitude of the output signal (larger output signals will clip at the supply voltage). The operating current sets the required value of base-emitter bias voltage (V_{BE}) and the values of the potential divider resistors R1 and R2 are chosen to provide a voltage of $V_E + V_{BE}$. The total resistance value should be such that the current through the resistors is at least ten times the base current.

Capacitors

For the common-emitter amplifier we bypassed the emitter resistor with a capacitor so that the feedback only

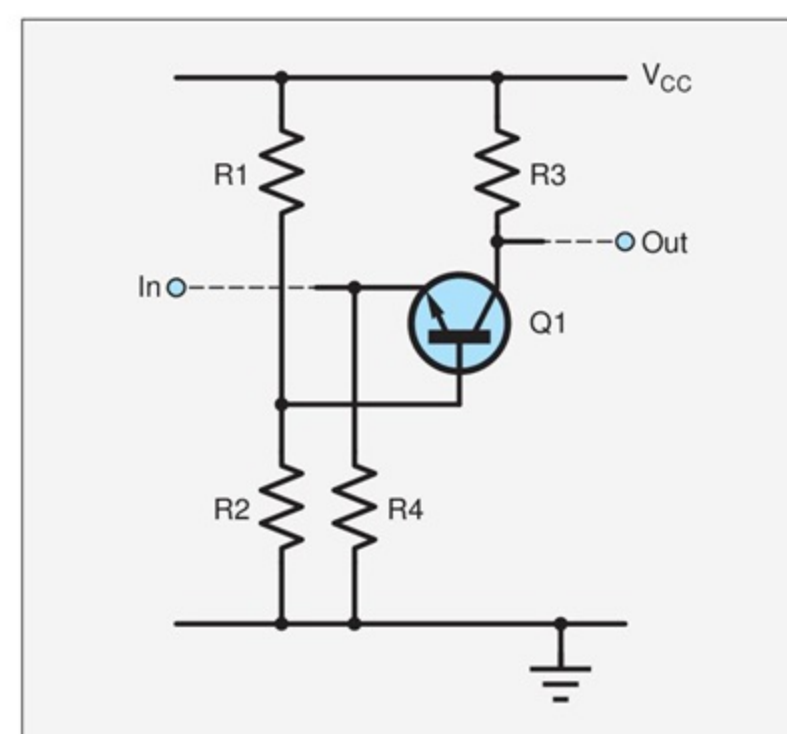


Fig.3. Common-base amplifier DC bias circuitry.

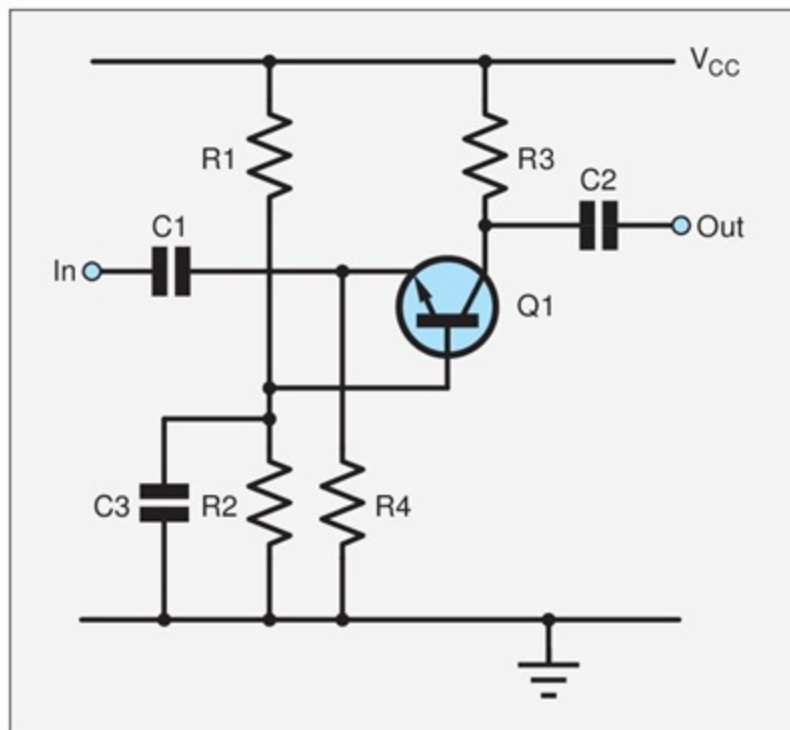


Fig.4. Common-base amplifier.

influenced the bias. For the common-base circuit we need to bypass the bias resistor connecting the base to ground (R2 in Fig.3). Note that in both cases, if you think of the capacitor as a short circuit at relatively high frequencies, then the bypass capacitor ensures that the common terminal of the transistor is connected to ground as far as AC signals are concerned – as it is in the configuration concepts shown in Fig.1. The bypass capacitor value should be selected to have low ‘resistance’ (impedance) at the lowest signal frequency the circuit will be used to amplify.

As with the common-emitter circuit, the input signal to the common-base amplifier is applied via a coupling capacitor so that any DC component of the input signal does not disrupt the bias. Similarly, the output is commonly connected via another coupling capacitor. Using the bypass capacitor discussed in the previous paragraph, and the coupling capacitors added to the circuit in Fig.3, we arrive at a practical implementation of the common-base amplifier, as shown in Fig.4. C1 and C2 are the coupling capacitors and C3 is the bypass capacitor. Fig.5 shows the common-emitter amplifier (with which people are generally more familiar) for comparison.

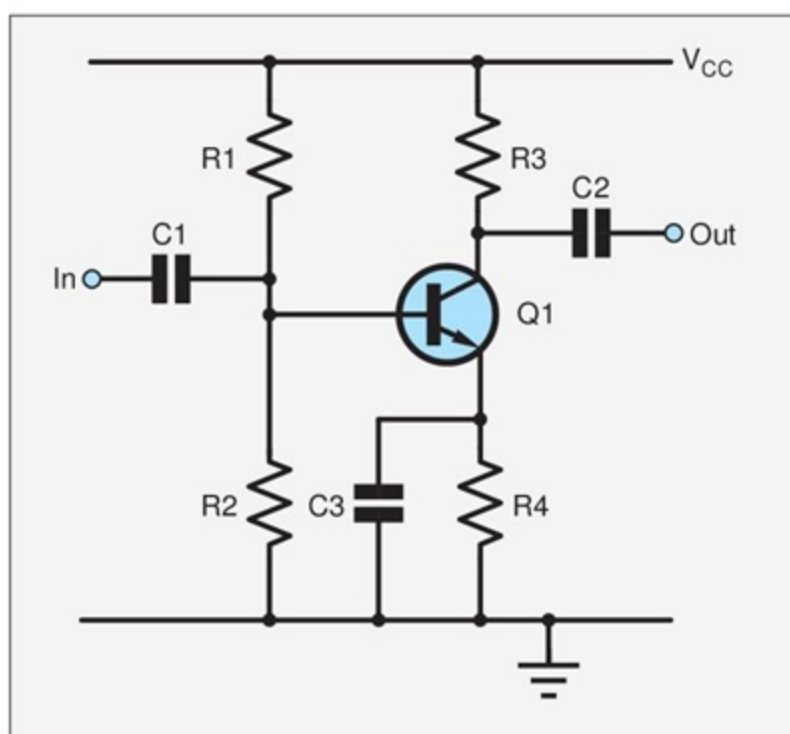


Fig.5. Common-emitter amplifier for comparison with the circuit in Fig.4. The differences are the input connection and the location of the bypass capacitor C3.

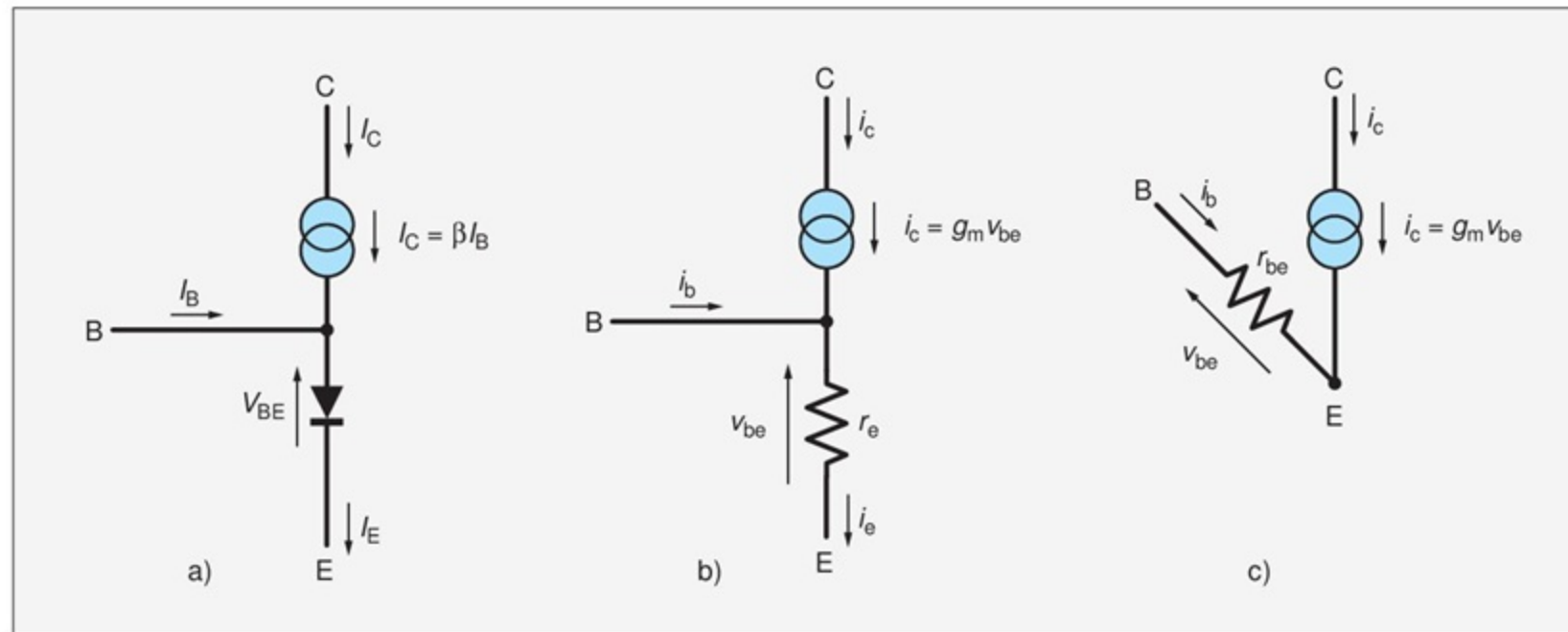


Fig.6. Transistors models: (a) simplified Ebers-Moll (b) small-signal model with r_e (c) small-signal model with r_{be} .

Models

In the previous articles we introduced the small-signal models that are often used to analyse transistor circuits. These are based on linearising a model that covers the full range of transistor operation at the operating point set by the bias. Fig.6 shows three transistor model circuits (which were shown in the first article). The full-range (or large-signal model) is shown in Fig.6a. At a particular operating point the diode has a certain effective resistance and, as long as the signal does not cause a large change in voltage or current, we can assume this value is constant. Replacing the diode with a resistor leads to the small-signal model shown in Fig.6b. Fig.6c shows an alternative version of the small-signal model, in which the resistance between base and emitter is arranged differently.

The models in Fig.6b and Fig.6c are electrically the same from outside of the transistor, but each is suited to different contexts. Fig.6c, which we used last month, fits naturally with common-emitter circuits – the input is across the base-emitter resistor (r_{be}) and the output current source is from collector to emitter. Thus, the emitter is the common connection in the model. Similarly, the model in Fig.6b fits with the common-base configuration – the input is across the emitter resistor (r_e) and the output current source is from collector to base.

Fig.7 shows the two small-signal models from Fig.6 redrawn in the conventional layout, which more clearly shows the base and emitter as the common connections. Note that if we draw a small-signal

model for the whole amplifier we need to include the other component too – as we showed for the common-emitter amplifier last month. The bypass resistors can be assumed to be effectively short circuits at signal frequencies, so the transistors’ common connection is grounded in the models for the circuits in Fig.4 and Fig.5.

Input resistance

From Fig.7, we see that a key difference between the common-base and common-emitter configurations is the input resistance (across which the input signal v_{be} is applied), which is r_e and r_{be} respectively. In the first article we noted that the relationship between these values was $r_{be} = (1 + \beta)r_e$. Thus, given that β is typically 100 or more for transistors used in small-signal amplifiers, we conclude that the input resistance of the transistor in common base is much smaller (by a factor of β) than that for common emitter.

The value of r_e is approximately $25/I_E$ at room temperature, with I_E in mA. In the circuit in Fig.4, R4 is in parallel with r_e , but since r_e is likely to be smaller than R4, r_e it will dominate the input resistance. With an operating current of 1mA the input resistance of the circuit in Fig.4 is around 25Ω. This situation sounds bad – often we want a large input resistance for a voltage amplifier, but, as we will see later, one advantage of the common-base circuit is its potential for providing wide bandwidth. High-frequency signals are often connected via cables with impedances in the tens of ohms (eg, 50Ω and 75Ω) which need to be matched to a circuit’s input impedance to prevent reflections. The common-base

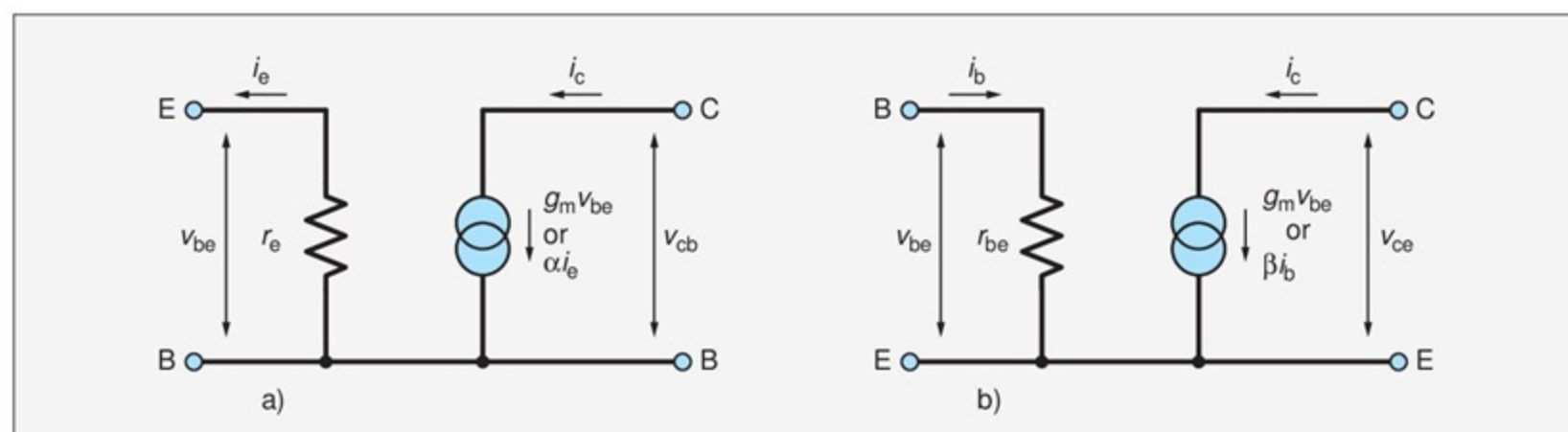


Fig.7. Small-signal models drawn with conventional layout (a) common-base configuration (b) common-emitter configuration.

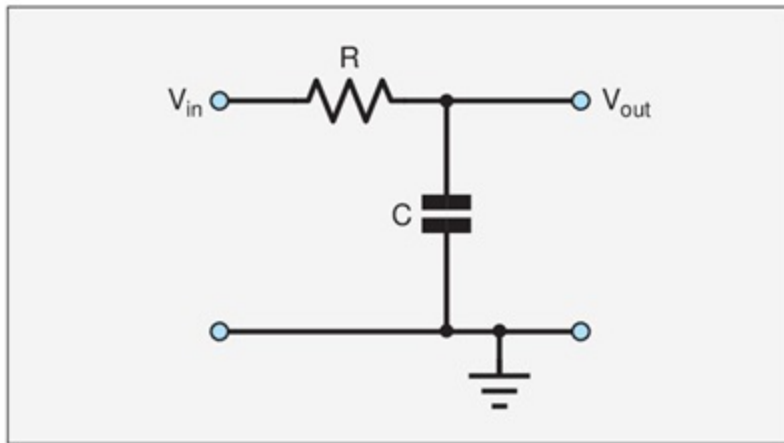


Fig.8. *RC* low-pass circuit.

circuit's input impedance is of the same order of magnitude as this, so the low resistance may not be as problematic as it seems in some applications.

The output current of the common-base amplifier can be represented as $g_m v_{be}$ when considering voltage amplification. This is the same as the common-emitter amplifier, and given the output circuit at the collector is effectively the same, the common-base amplifier can provide high voltage gain like the common-emitter amplifier.

Frequency response

So far, in our discussion of transistor circuits we have not discussed the effect of frequency in depth. In general, we need to consider both the high-frequency and low-frequency response of an amplifier to see if meets our requirements. We will look at both these in the rest of this article with reference to both the common-emitter and common-base circuits. At low frequencies the situation is similar for both circuits, but there is a significant difference at high frequencies.

Capacitors and inductors are components whose effective resistance vary with frequency and we refer to the effective resistance of frequency-dependent components as 'impedance'. For a resistor, Ohm's law provides a simple relationship between voltage across and current through a resistor ($V = IR$) and a similar relationship applies to impedances. However, a resistor does not change the relative timing of the current and current voltage, but inductors and capacitors (and impedances in general) do – causing a shift in time of the AC current signal with respect to the voltage signal (phase shift). This makes a full analysis of a circuit containing impedances more complex than one with just resistances; however, in some cases we can keep things simple and only use the magnitude of the impedance (not considering

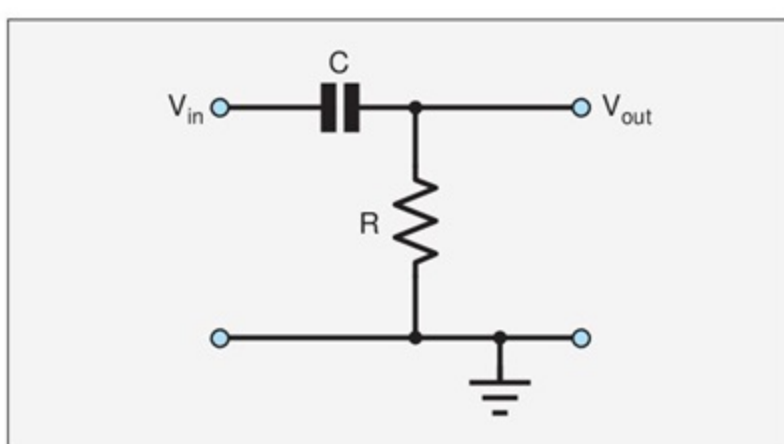


Fig.9. *RC* high-pass circuit.

the phase shift) in Ohm's law and similar calculations. For a capacitor with capacitance C , the effective resistance (magnitude) at frequency f is equal to $1/2\pi fC$.

Combinations of resistors and capacitors, as we see in Fig.4 and Fig.5, result in circuits with a frequency-dependent response – that is, the input/output relationship (gain) will vary with frequency. A simpler circuit is shown in Fig.8 – this is well known as an *RC* low-pass filter. At very low frequencies, the impedance of C is very large – it is more or less an open circuit, so all of V_{in} passes to V_{out} . At very high frequencies, the impedance of C is very low – it is more or less a short circuit, so V_{out} will be close to zero. What constitutes 'low' and 'high' frequencies depends on the values of R and C . A frequency of particular interest is the defined cut-off frequency (f_c), which is given by, $f_c = 1/2\pi RC$. At this point, the output power is half that at very low frequencies. The circuit in Fig.9 is similar to Fig.8, but it is a high-pass filter – blocking DC and low frequencies but letting high frequencies through. The same cut-off frequency formula applies for the cut-off frequency

We can form a small-signal model with all the circuit components present (eg, for Fig.4 or Fig.5) and perform the circuit theory algebra to work out formulae for the complete frequency response – with a lot of components this may get complex or messy. Alternatively, we can consider just one part of the circuit and look at the model structure to get at least an approximate idea of the influence of particular components.

Low-frequency cut-off

We have used coupling capacitors to make sure that only the AC part of the signal is input to our amplifiers, preventing possible disruption to the bias. These will form high-pass filters with resistances present in the circuit or system. Consider the input coupling capacitor for the common-emitter amplifier in Fig.5 (C_1) – the bias resistors R_1 and R_2 will be in parallel with the transistor's r_{be} , (remember that the power supply is a short circuit in the small-signal model). The parallel resistance value will form a high-pass filter like Fig.9 with the coupling capacitor. From this, we estimate the low-frequency cut-off point due to the coupling (or select a capacitor to give us the desired cut-off). This result will not necessarily tell us the low-frequency cut-off for the whole circuit, as other components such as C_3 will also influence this; however, it will provide some idea of the right value for C_1 .

For example, using the values for Fig.5 from last month, we have $C_1 = 10\mu\text{F}$, $R_1 = 16.2\text{k}\Omega$ and $R_2 = 3.5\text{k}\Omega$. To estimate r_{be} , we use the previously mentioned $r_e = 25/I_E$ with 1mA operating point and a

β of approximately 300 from the LTSpice model to give $r_{be} (\approx \beta r_e)$ at about $7.5\text{k}\Omega$. The resistances in parallel are about $2.1\text{k}\Omega$, giving a cut-off of around 7.6Hz . If our specification was for a minimum frequency of 100Hz , this would be fine, but if we had used $C_1 = 0.1\mu\text{F}$ then the input coupling cut-off would have been too high at around 760Hz .

Transistor capacitance

The low-frequency behaviour of the circuits we are discussing depends on components we have specifically included in the design. For high frequencies we need to look at what are known as parasitic components – the unwanted resistance, capacitance and inductance inherent in all components and wiring. In this case we are particularly interested in the internal capacitances of the transistor, which are shown in Fig.10. The base-emitter and base collector capacitances (C_{be} and C_{bc}) are the most significant, being much larger than the collector-emitter capacitance. In typical amplifier circuits, C_{be} depends on the capacitance of the forward biased base-emitter junction and the charge held in the transistor's base region during conduction. C_{bc} is the capacitance of the reverse biased base-collector junction. Like many other transistor parameters these values vary with operating point.

The Miller effect

Before discussing the effect of these capacitances on the amplifier circuits we need to look a piece of circuit theory called the Miller theorem. This relates to removing an impedance (Z), which is bridging two parts of a linear circuit network (N_1 and N_2) and replacing it with two impedances (Z_1 and Z_2) which are each connected to only one side of the 'bridge' (see Fig.11). The circuit is linear, so the two voltages are related by $V_2 = KV_1$ (we can think of K as being the gain or attenuation that the circuit has between these two points). The new circuit is equivalent to the original in that the voltages and currents in N_1 and N_2 remain the same. The theorem provides the values of Z_1 and Z_2 in relation to Z and K , specifically:

$$Z_1 = Z(1 - K)$$

$$Z_2 = Z(1 - 1/K)$$

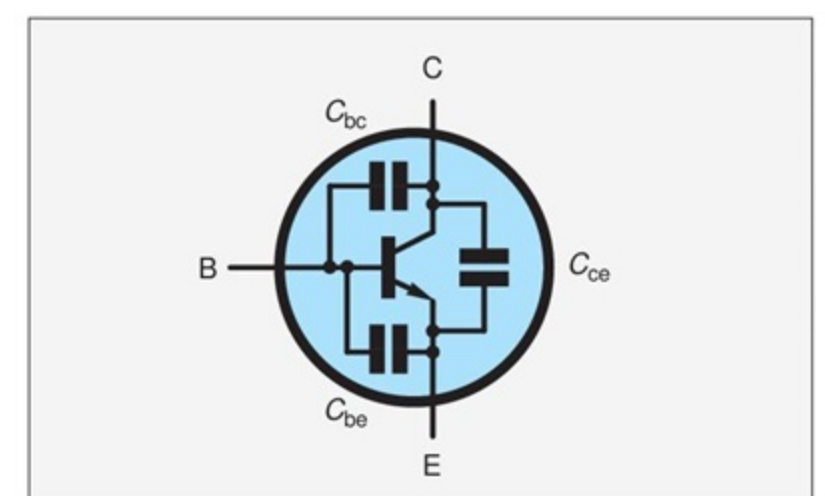


Fig.10. Bipolar transistor capacitances.

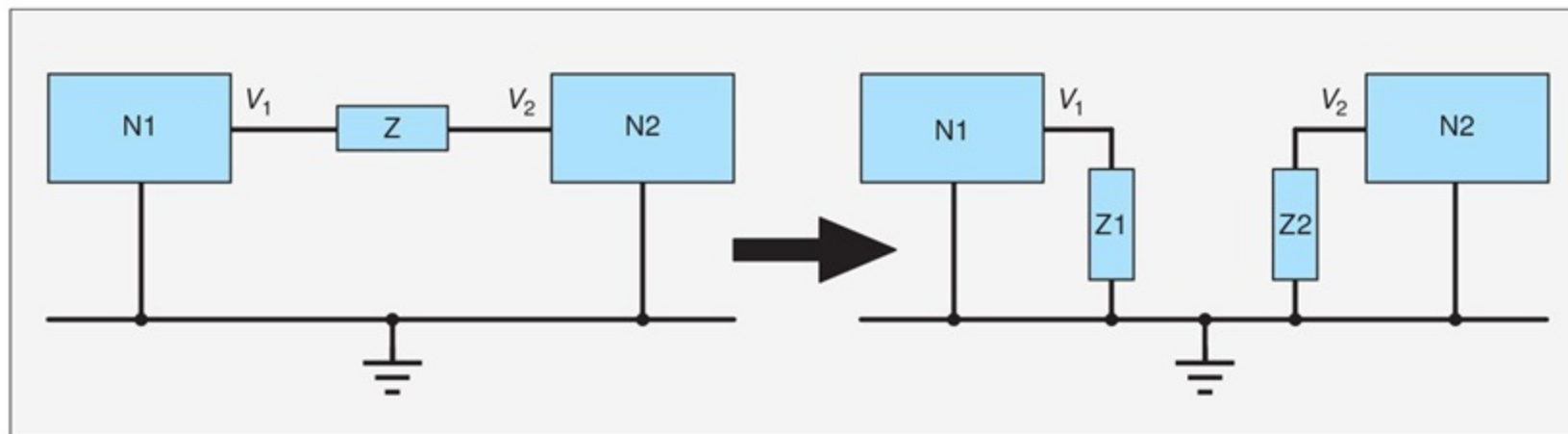


Fig.11. The Miller theorem.

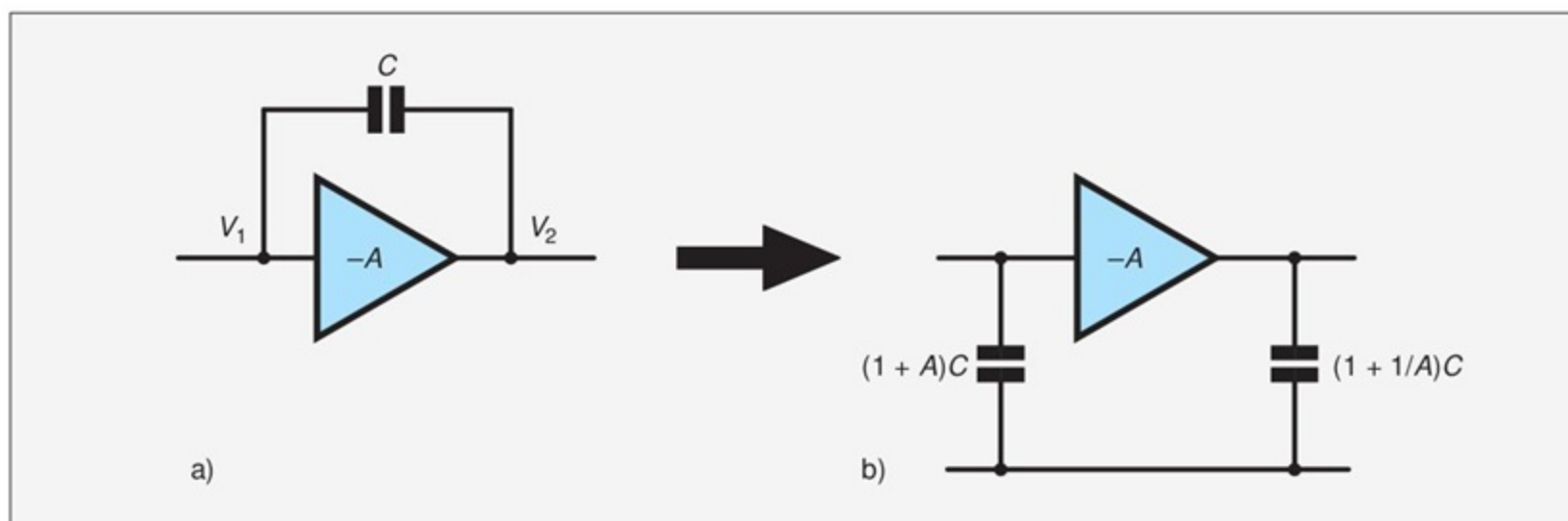


Fig.12. The Miller effect.

The Miller theorem has a number of applications, but here we are interested in the effect of a feedback capacitance on the effective input capacitance of amplifiers. Consider an amplifier (with gain $-A$) with a capacitance (C) between input and output, as shown in Fig.12a. We consider a negative gain to cover the case of an inverting amplifier (or situation where the capacitance appears as a negative feedback path). From a Miller theorem perspective, N1 is the amplifier's input circuitry and N2 is its output circuitry – these being parts of a 'linear circuit network', which in this case is the whole amplifier. We have a relationship between the two voltages, V_1 and V_2 set by the amplifier's gain, that is $V_2 = -AV_1$, so the Miller K parameter is equal to the amplifier gain (ie, $K = -A$) in this case.

In Fig.12a the Miller impedance (Z) is the feedback capacitor (C) so we can write $Z = 1/2\pi fC$. Applying this to the Miller theorem equation $Z_1 = Z/(1-K)$, also with $K = -A$, as just discussed, we get:

$$Z_1 = (1/2\pi fC) / (1 - (-A)) \\ = 1/2\pi f(1+A)C$$

This is equivalent to a capacitor with value $(1 + A)$ times the original capacitance. Similarly Z_2 is equivalent to a

capacitor of value $(1 + 1/A)C$. This leads to the Miller equivalent circuit shown in Figure.12b. The capacitance at the input is multiplied by the gain, which for a large gain results in a large effective input capacitance that may have a significant impact on the circuit. This is known as the 'Miller effect'. The effective input capacitance is called the 'Miller capacitance'.

High-frequency cut-off

Fig.13 shows the generic situation for a signal source connected to an amplifier. Without any input capacitance, the source and input resistance act as a potential divider, reducing the effective input voltage for small r_{in} and/or large r_s at all frequencies – this is why the low input resistance of the common-base amplifier is potentially problematic. If we also consider input capacitance, we see that because it is in parallel with r_{in} it reduces the input impedance and hence the overall gain at high frequencies. It acts as a low-pass filter with the source resistance – the larger the capacitance the lower this cut-off. As we have just seen, the Miller effect causes a small feedback capacitance to act as a large input capacitance, so amplifiers with significant Miller capacitance will tend

to have lower higher-frequency cut-off (lower bandwidth) than similar amplifiers without this effect present.

From Fig.13 it appears that if the source impedance is very low then the capacitor may cause minimal attenuation. However, transistors have another parasitic component – the base resistance, which is located between the external terminal and the base-emitter resistance and capacitance. In the context of the Fig.13 model, it is in series with the source resistance, so it will act in that capacity, even if the source itself has very low resistance.

Fig.14 shows a small-signal model for a common-emitter amplifier with the significant transistor capacitances added. R_L is the collector load resistor, R_3 in Fig.5. C_{be} is in parallel with r_{be} and bypasses the input to the base at high frequencies, reducing the effective current gain of the transistor as frequency increases (the current in C_{be} does not control the collector current, unlike the normal base current). The cut-off frequency related to this RC combination occurs when the magnitude of impedance of C_{be} equals r_{be} and is given the symbol f_β . Further increases in frequency reduce the current gain further, with it eventually reaching unity at a frequency referred to as the transistor's transition frequency, f_T – this value gives an indication of the highest frequencies at which a transistor can be used.

Fig.14 shows that the base-collector capacitance is between input (base) and output (collector) for the common-emitter amplifier. It therefore acts as a Miller capacitance and has a significant effect on bandwidth, as discussed for generic case earlier. Fig.15 shows a small-signal model for a common-base amplifier with the significant transistor capacitances added. Here we see that there is no significant Miller/feedback capacitance – C_{bc} is across the load. This provides the common-base amplifier with the potential to provide high gain at very high frequencies, ultimately limited by the transistor's f_T . There is still possible attenuation due to C_{bc} and R_L , but RF circuits will often use an inductor and capacitor in the collector, providing a tuned load that can take C_{bc} into account.

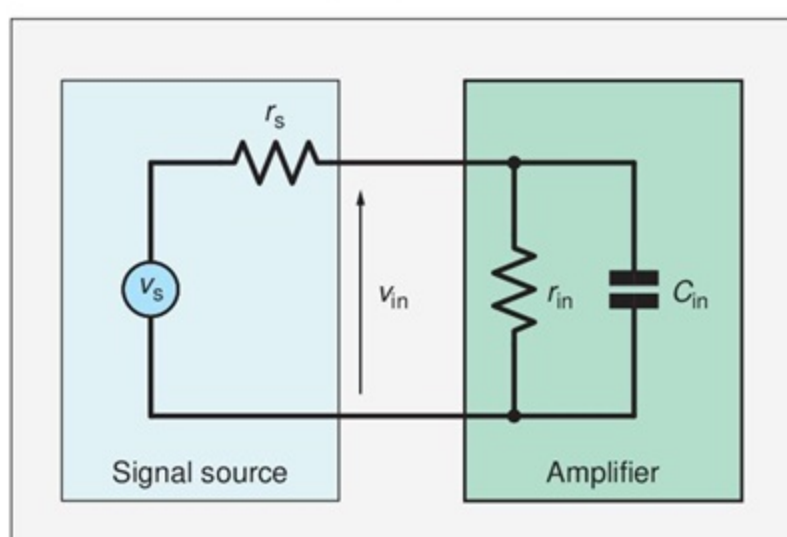


Fig.13. Generic connection of a signal source to an amplifier input.

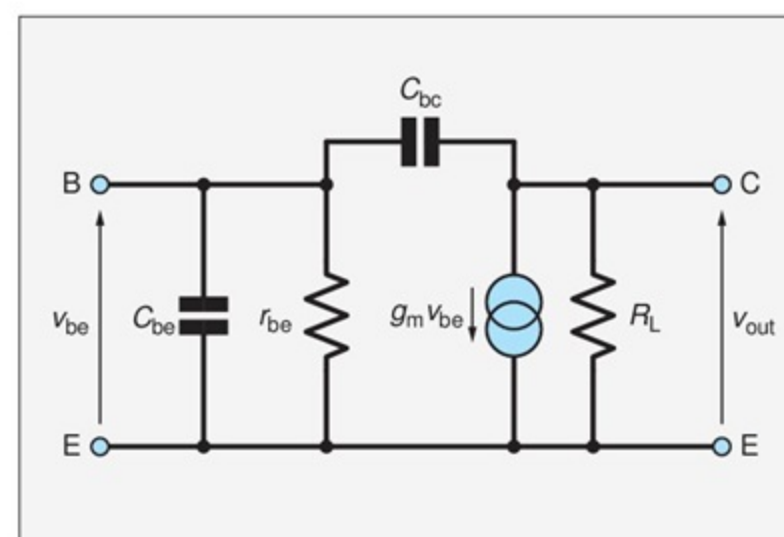


Fig.14. High-frequency small-signal model for a common-emitter amplifier.

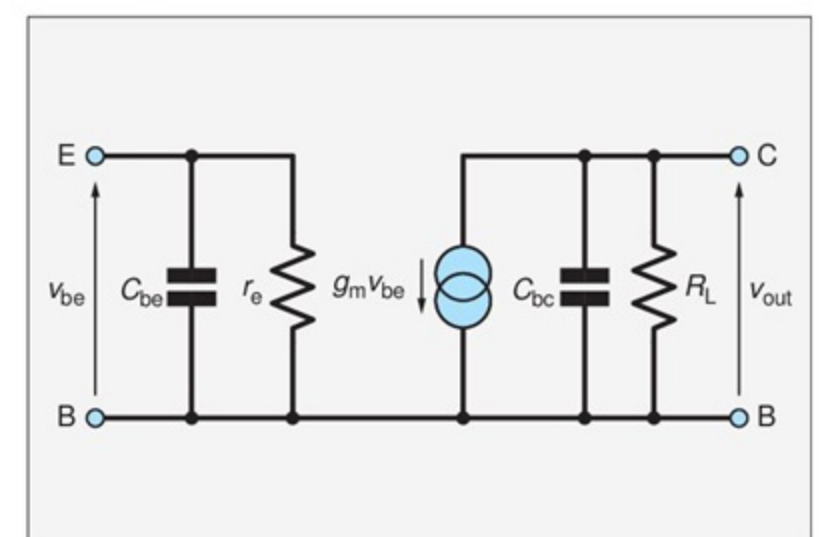
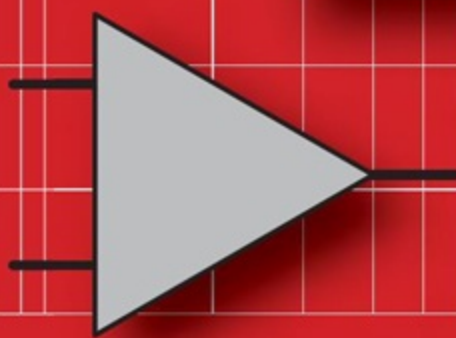
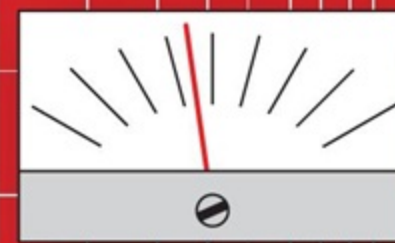
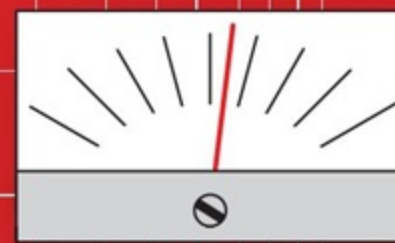


Fig.15. High-frequency small-signal model for a common-base amplifier.

AUDIO OUT



By Jake Rothman

Designing Hi-Fi mini-monitor loudspeakers – Part 1



Fig.1. A current production LS3/5A by Rogers.

It has long been a British audio tradition to design small but accurate Hi-Fi speakers, known as 'mini-monitors'. The concept originated in the BBC, where they undertook world-leading research and development in speaker systems in the 1960 and 1970s. This led to the development of a two-way small speaker to be used in outside broadcast vans and

radio studios, known as the 'LS3/5A'. A tried and tested speaker, it will be the inspiration for this series of articles. We'll start this month with a little background and history of the LS3/5A, as well as looking at some of the technical considerations in speaker design. (Surprisingly, the papers originating from this licence-payer funded effort are available for download from the BBC website. It's an essential read for any aspiring loudspeaker designer. Nowadays,

the BBC does less technical research and is content to use consumer technology such as Skype and commercial speakers.)

Unlike most consumer electronics, loudspeakers have remained rather expensive and may even have gone backwards in some areas of sound quality. I don't know what has happened, but it's almost as if good speakers are now

only bought by elite Hi-Fi enthusiasts and professional recording circles. The solid wooden speakers gracing most living rooms in the 1980s have been replaced by plastic tat. However, over the next few months, I'll show how to make your own and put back some of the lower colouration exhibited by older BBC and KEF designs. There will be six options to build, most of which pay homage to the BBC LS3/5A – see the box opposite.

The unusual LS3/5A name is based on the BBC convention. 'LS3' indicated it was a loudspeaker (primarily) intended for outside broadcasting vans, while the 'LS5' was used for studio monitoring. The number after the stroke is the model number (5), and the final letter denotes alterations to the original specification, of which there was only one – hence the 'A'.

An unusual aspect of the LS3/5A is that since the BBC was not interested in manufacturing speakers, from 1975 they licensed production to a small number of British companies. A modern incarnation of the original LS3/5As from Rogers is shown in Fig.1, while Fig.2a and Fig.2b show 1960s adverts for older mini-monitors, the Maxim from Goodmans



Fig.2. 1960s adverts showing the first successful British mini-monitor speakers: (left) Goodmans Maxim, (right) the Celestion's Ditton 10.



Fig.3. A derivative of the LS3/5A, the round Jim Rogers JR149. A very low-colouration cabinet.

and the Ditton 10 from Celestion. The uniquely round JR 149s (Fig.3) as well as LS3/5A-inspired Proacs, Spondors and Harbeth HL-P3s now command high prices on eBay.

The LS3/5As produced by Rogers were generally considered the best, and recently these have just been reintroduced using Chinese-made versions of the venerable KEF drivers. The cost is around £2800.00, moving them out of the engineering sphere into the realms of Rolex watches.

System synergy

The principles of mini-monitor design are embodied in the options listed in the *PE Mini-monitor* box above, which are inspired by the original LS3/5A.

A passive speaker system is a collection of parts and subsystems that interact and combine to create a coherent

PE Mini-monitor build options

1. Authentic BBC LS3/5A – all components from Falcon Acoustics (FA)

Cabinet – kit cabinet, BBC spec from FA online shop

Driver – BBC spec from FA online shop (KEF B110A)

Tweeter – BBC spec from FA online shop (KEF T27)

Crossover – BBC spec from FA online shop

Total cost approx. £850: equiv to £2300 speakers

2. Vifa (Danish) driver design – good, small mini-monitor – not an ‘LS3/5A’

Cabinet – pre-assembled unpainted MDF cabinets from Earworm Records

Driver – Vifa drive units (BC14SG49-08), from Earworm Records

Tweeter – Vifa tweeter (TC26SF05-06), from Earworm Records

Crossover – assembled X-over built on wood from Earworm Records

This design is essentially assembled, including driver, tweeter and crossover, but I will offer tips for improvements. Approx £200 per pair for assembled units + p&p: equiv to £600 speakers

3. DIY Vifa design – option 2, but with *PE* design for cabinet and crossover

Cabinet – *PE* plywood design – 9-inches deep with baffle for Vifa units

Driver – Vifa drive units (BC14SG49-08)

Tweeter – Vifa tweeter (TC26SF05-06)

Crossover – built on *PE* crossover PCB

4. *PE* Mini-monitor, LS3/5A style (FA version)

Cabinet – *PE* plywood design (9-inches deep) with baffle for FA driver

Driver – same driver as LS3/5A kit (No.1) (KEF B110A)

Tweeter – different tweeter from No.1 kit – this will use an SEAS design

Crossover – built on *PE* crossover PCB

5. *PE* Mini-monitor, LS3/5A style (Wavecor version)

Cabinet – *PE* plywood design (9-inches deep) with baffle for Wavecor units

Driver – Wavecor

Tweeter – Wavecor

Crossover – built on *PE* crossover PCB

6. Active *PE* Mini-monitor, LS3/5A style (circuit works with all of the above)

The active option will be designed on a single PCB and will incorporate much of the special detail on wiring layout, power amplifiers and power supplies I’ve previously described in *Audio Out*. This circuit will not only drive the *PE* Mini-monitor but also pretty much any small two-way speaker system. The design of the *PE* plywood cabinet ensures activation only requires replacing the rear panel, which will include a cutout for the heat-sink, IEC mains connector and XLR socket.

whole. As well as the drivers, there is the cabinet and a special circuit called a crossover, which directs the right frequency ranges to each driver. Just as in a well-tuned car, all these parts need to be optimised to work together. There is no point mounting a £100 bass driver in a shoe box.

If you want to make your own design using alternative drive units, you will need to invest in some frequency response measuring software or use an old analogue plotter, such as the Neutrix Audiograph (Fig.4) in an anechoic room (in my case, a loft lined with mattresses) shown in Fig.5.



Fig.4. To plot the frequency response of a speaker you need at least a signal generator and dB-reading multimeter. (Left) I use a Neutrix Audiograph 3300 from 1981; (right) the Neutrix and a constant-current generator used to measure an impedance curve.



Fig.5. To minimise room reflections when taking frequency response measurements it's necessary to line the walls with acoustic absorbent material. Shown here in my attic, mattresses help provide almost anechoic conditions above a few hundred hertz. The photo shows a Meridian M2 active system being tested.

First, we need to cover some speaker basics and terminology. Loudspeaker design and construction is multidisciplinary; covering acoustics, mechanics, materials science, adhesives technology, magnetics and even woodwork. For passive designs, electronics is a small part of what is essentially an electro-acoustic system. It is still very much craft based and can offer real hands-on building satisfaction. (I've found speaker building is an excellent way of teaching technology to disaffected young men!)

Frequency range, woofers and tweeters

Audio is unusual among physics-based technologies in that it covers three decades of frequency range, a 1000 to 1 ratio – from 20Hz to 20kHz, with

corresponding wavelengths from 17m to 17mm. Compare this with the spectrum of visible light, which has a ratio of just 1.8 to 1.

This complicates the physical requirements for optimum sound propagation because very different considerations need to be observed at opposite ends of the audio spectrum. For adequate low-frequency reproduction a speaker needs to have a large surface area of at least 70cm² (10 square inches) and be able to move back and forth about 12.5mm (half an inch). If it has a larger area, it doesn't have to move so much – it is the total air displacement that matters.

For high frequencies, it is the moving mass that is important, since the diaphragm has to move fast with no inertia. A small area of about 2cm² is adequate,

since the vibration is coupled more efficiently to the air at high frequencies, which can be considered to be a form of acoustic impedance matching.

These two very different design requirements are the reason why all Hi-Fi speaker systems are composed of at least two drive units, one optimised for bass, and the other optimised for treble. These drive units are called the 'woofer' and 'tweeter' respectively, and such a system is described as 'two-way'. Typically, the woofer will be fed frequencies from 20Hz to 3kHz and the tweeter from 3kHz to 20kHz.

Crossovers

To make a two-way system work effectively electrical filters are required to steer signal frequencies to the correct speaker. The simplest system is a capacitor in series with the tweeter, typically 2.2µF to produce a 5kHz high-pass filter when used with an 8Ω tweeter. This prevents low-frequency currents from destroying the tweeter's small low-mass voice-coil and diaphragm. (Note that in music there is much more low-frequency energy than high. This is why the tweeter voice coil can have a thermal rating of only a few watts, even if it is used in a system powered by a 50W amplifier.)

For the bass, the low-pass filter can simply be the mechanical roll-off of the woofer – in other words, for a very simple crossover the woofer has no electrical components. This system can work surprisingly well, such as in the Acoustic Research AR7. However, for good quality crossovers, a tweeter capacitor is not enough, and the bass unit benefits from a filter. This is because the woofer's mechanical high frequency roll-off is poorly defined. It can vary widely between individual drive units and may often increase with level. For effective filtering, at the minimum, a series inductor is needed. Additional reactive components are also needed to achieve steeper slope filtering and for tuned circuits to remove peaks. Inductors have to be used because an RC low-pass filter would have unacceptable losses due to the series resistance. An inductor has a low impedance at bass frequencies allowing them through, while its rising reactance at high frequencies blocks high-frequency signals without any power/heat losses.

Unfortunately, the inductor is the least 'perfect' passive component; having significant DC resistance, distortion (due to hysteresis and vibration), cost and large physical size. These deficiencies are typically an order of magnitude worse than capacitors. However, in a passive crossover we have no choice but to use inductors. (Active filters avoid the need

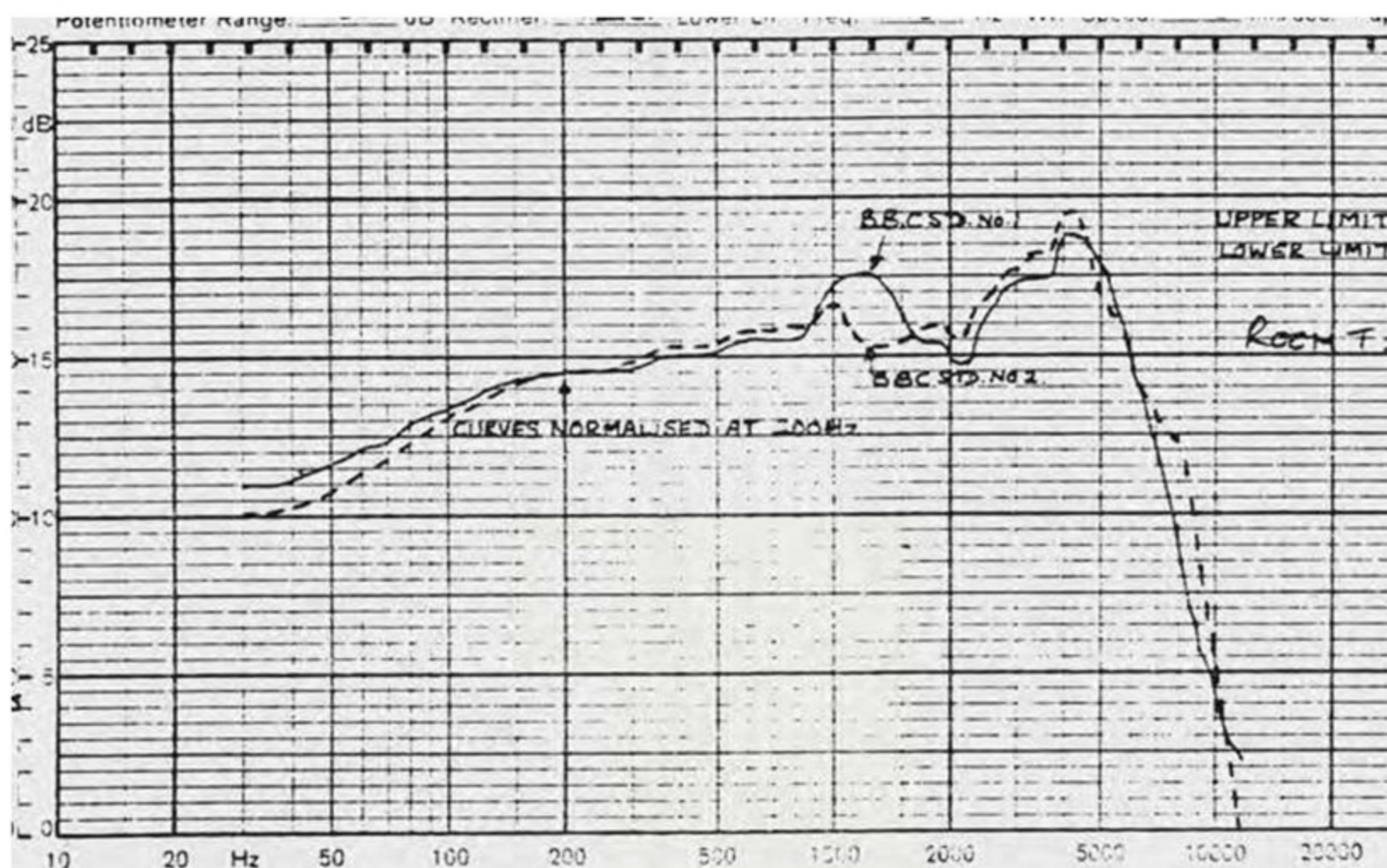


Fig.6. The raw frequency response of the B110A bass unit used in the LS3/5A in its cabinet. This needs considerable correction by the crossover filter before it can be used. This old BBC curve from Malcolm Jones shows the acceptable frequency response variation between units. Note that loudspeaker frequency response curves always have log axes, with the vertical axis expressing level in decibels (dB) and frequency along the horizontal X axis. Unfortunately the BBC based their design on a particularly good sample, giving KEF mass-production problems when orders arrived.

for inductors and can use cheap, accurate and compact resistors and capacitors, but of course a power supply is needed, which is not available in a passive system. For active speakers, however, this is the preferred design route and inductors are avoided.)

Crossover frequency

A sensible dividing point between the two drivers has to be chosen depending on the frequency range of the drivers and this is the 'crossover frequency'. Ideally, the response of the drivers should extend by an octave either side of the crossover frequency. However, this is rarely the case, especially with bass drivers, where there will typically be a peak followed by sudden roll-off above. The KEF B110A bass unit used in the LS3/5A is no exception, as shown in Fig.6. (The corresponding tweeter curve for the Kef T27 is given later in Fig.31.)

The crossover frequency is usually placed between 2kHz and 4kHz for standard-sized drive units. Such woofers are typically 80-200mm (4-8 inches) in diameter and tweeters sized 18-30mm (0.75-1.25 inches). If bigger woofers are

used (>200mm) to achieve higher sound levels, it becomes necessary to subdivide the frequency band further by adding a mid-range unit (called a 'squawker' in US audio circles). This mid-frequency crossover point is typically from 200 to 700Hz. Note that in two-way systems it is more technically correct to describe the woofer as a 'bass-mid' unit.

One other crossover design point is important – since a crossover is basically two filters; a low-pass and a high-pass, it makes sense to modify these filters to flatten out, or 'equalise', any bad trends or peaks in the frequency response of the speakers they are designed for.

Colouration

A loudspeaker that exhibits a particular tonal aberration, usually as a result of unwanted resonances, is described as 'coloured'. Subjective terms are often used to describe these effects, depending on the frequency area affected. All cone and cabinet materials have characteristic colourations. A typical speaker colouration can be emulated by talking into a plastic cup. Tapping a polypropylene packaging container will produce a sound characteristic of a polypropylene cone. A foil cake container will sound like an aluminium cone. Legend has it that Dudley Harwood was inspired to

invent the plastic cone loudspeaker by a plastic cup in the BBC canteen. I've noticed speaker designers are always tapping and listening to things. It raises eyebrows when my wife and I are selecting furniture or properties!

Break-up modes

In theory, loudspeaker diaphragms should vibrate like a piston to give predictable results. Since no material is infinitely rigid, this is impossible above a certain frequency. Making the material into a cone/triangle shape greatly increases the rigidity before it deforms. Typically, bending and unpredictable vibration modes occur around a few hundred hertz for a 200mm (eight inch) cones and about 700kHz for a 110mm. Fig.7 to Fig.13 show a series of these modes as the frequency increases. Each mode is usually associated with a glitch in the response curve of the driver. These 'break-up modes' as they are commonly called, give rise to the characteristic sound of loudspeakers. It can be exploited in an artistic way, such as in guitar speakers. For Hi-Fi speakers it is a serious problem. In the US, audio engineers have a very descriptive term; they describe the sound as 'cone cry'. Like turbulence, the mathematics is complex and chaotic. Models exist but I'm



Fig.7

Break-up modes revealed on an 8-inch lightweight, straight-sided Audax paper cone speaker. The cone was brushed with talcum powder (Fig.7) then driven with a $5W_{rms}$ sinewave, gradually increasing in frequency, but stopping when resonant modes were encountered. The powder remains on areas of the cone that are stationary, revealing the vibration pattern.

Fig.8. First radial break-up mode at 820Hz

Fig.9. 1.3kHz

Fig.10. 2.1kHz

Fig.11. 2.75kHz

Fig.12. 4.25kHz circular break-up mode

Fig.13. 6.6kHz



Fig.8



Fig.10

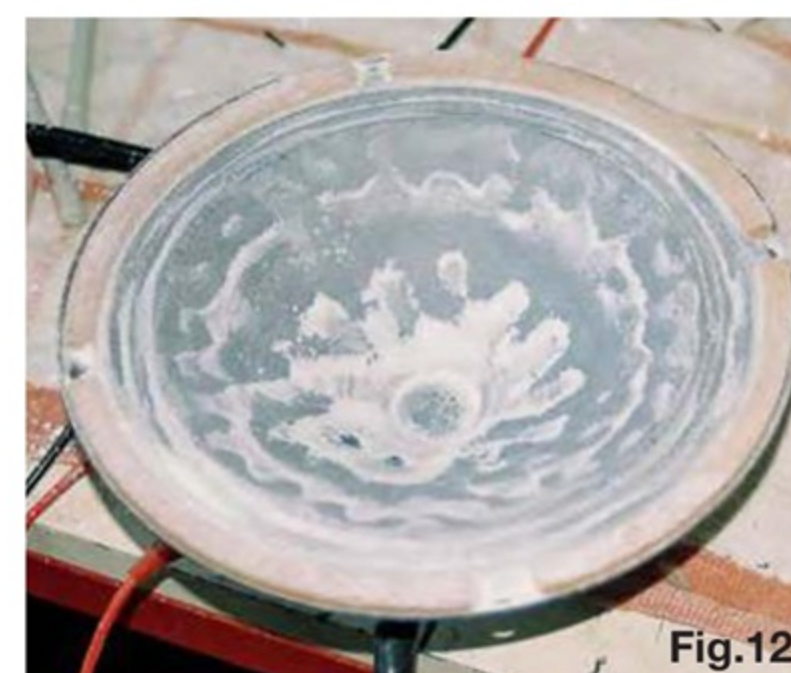


Fig.12



Fig.9

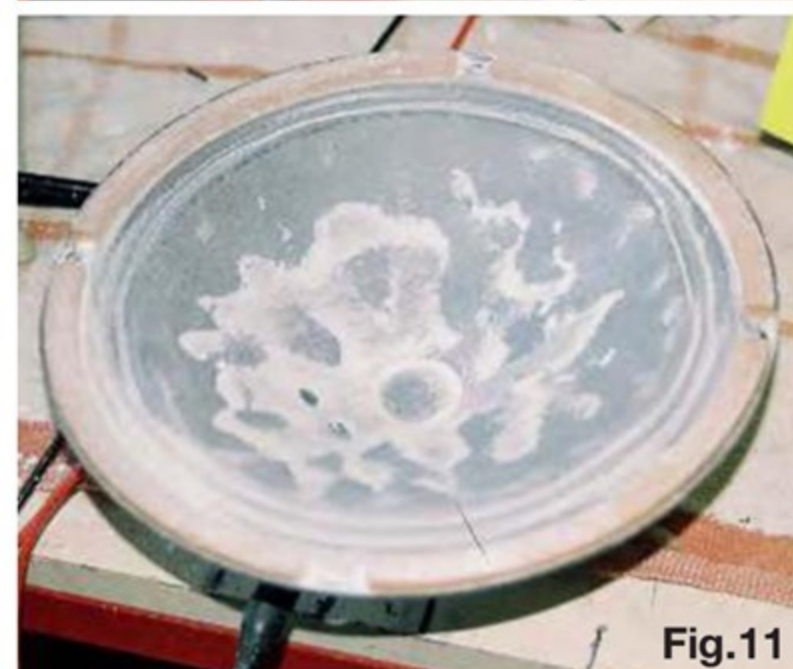


Fig.11

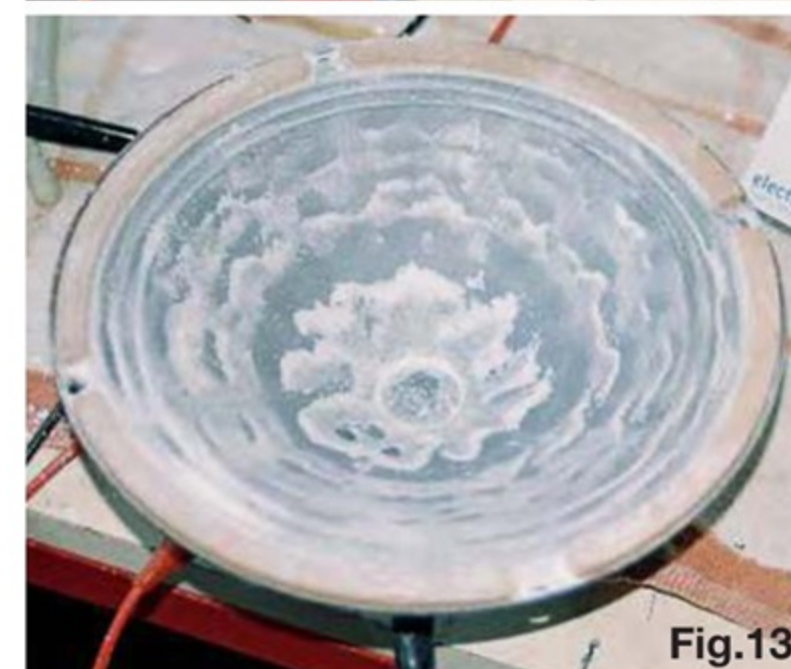


Fig.13

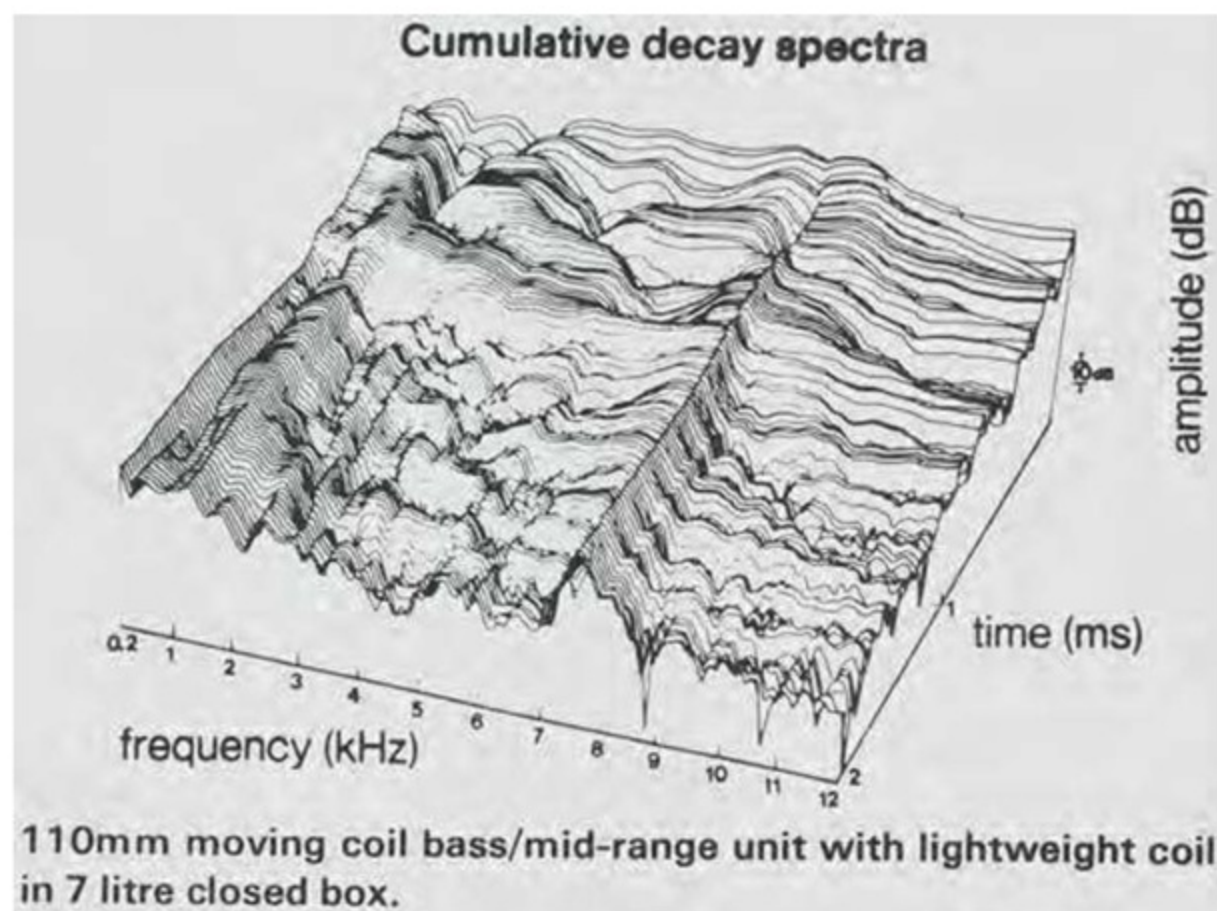


Fig.14. A 'waterfall' frequency response time graph. KEF pioneered the use of 3D waterfall graphs to show delayed resonance, with a third Z axis for time. This experimental mid-range unit shows a resonance at 7.4kHz that does not appear in the initial frequency response sweep, but then becomes quite obvious on the subsequent decay spectra.

not convinced they are successful yet. I have a piece of software which simulates the response of a Celestion G12 guitar speaker, but it is oversimplified. It's akin to basic vibration patterns on violin bodies, and explains why there is no Stradivarius app for the iPhone.

The cone shape is also important. A curved cone is used in most Hi-Fi bass-mid units because although the cone breaks up at a lower frequency, the modes are less severe. Also, the radiating area of the cone gets smaller as the frequency increases, extending the high frequency response and widening the dispersion. Straight-sided cones are better for bass-only units as they are stiffer and can handle more force at the apex.

When compensating for these effects, equalisation (EQ) can only reduce the excitation of the resonant modes. Once they have been kicked off, they can continue to ring for a while after the signal has ceased. This is called 'delayed resonance' and can be displayed on a 'waterfall graph', as shown in Fig.14. They can sometimes be heard 30dB down. There is not much point in just equalising the speaker to be flat. To make it *sound* flat,

the EQ has to take stored energy into account. Many speaker designs just put a bigger dip than theoretically necessary in the frequency response around the area of mid-range break-up modes until it 'sounds' realistic. Being able to quickly record and playback snippets of sounds on a computer is very useful for this 'live vs reproduced' testing technique.

Cabinet

The loudspeaker cabinet is a vital part of the design (and probably the part that is least understood and most feared by electronics enthusiasts). It is not just a box to hold the drivers, it also has a vital acoustic function of providing bass loading. A speaker cannot radiate bass or long wavelengths unless some means is provided to prevent the out-of-phase sound from the rear of the diaphragm cancelling the sound at the front. In most small speakers this is achieved by mounting the bass unit in a sealed box. This prevents phase cancellation, but it has a defect: the air cushion of the trapped air makes the cone suspension stiffer. This has the effect of raising the resonant frequency. Below the resonant

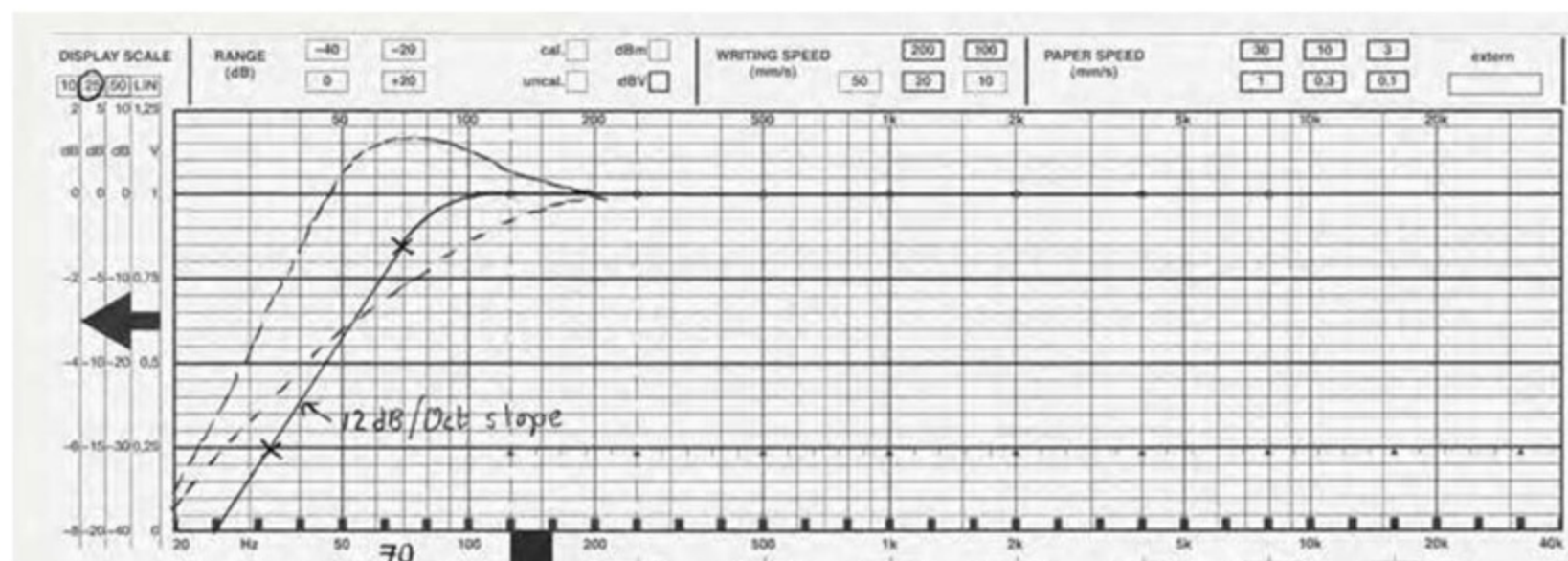


Fig.15. Ideal second-order roll-off obtained using closed-box loading. For a Q of 0.707, the -3dB point is at 70Hz. The dotted lines show the effect of overdamping (bass loss) and underdamping, giving peaking.



Fig.16. Flush mounting drivers helps minimise comb filtering effects in the upper frequency response due to stepped diffraction effects. These cabinets for Wavecor drivers had fronts made from two pieces of plywood sandwiched together.

frequency, bass reproduction falls away rapidly. A good demo of this effect is to place a plastic container, such as a Tupperware bowl, upside down in water and tap it. It will resonate a bit like a bass drum. The frequency will go higher the less air is trapped underneath. Try this next time you are doing the washing up.

Sealed box

A speaker in a closed box exhibits a high-pass filter response with a roll-off of 12dB/octave, as shown in Fig.15. Ideally there should be no peak at the roll-off point, causing boom, nor should it start to roll off too early, giving bass loss. These effects are determined by the total damping, or 'Q' of the system. Q, or 'quality' is a measure of how tightly defined the system resonates. A high Q means resonance falls off very sharply either side of the resonant frequency. A low Q means the opposite, and resonant effects are apparent for a much wider range of frequencies. The speaker's overall Q is determined by several factors, the electromagnetic Q of the driver, the mechanical Q of the drivers suspension and the amount the 'air spring' pushes up the resonance. If the system is slightly over damped with say a Q of 0.5, bass boost from a normal Baxandall bass control will fix it. Such bass boost can't be applied if the Q is high (much over 0.5). The optimum value giving the flattest response is the same as a Butterworth filter, with a Q of 0.7.

Reflections

Another aspect of cabinet design is the reflections and standing waves that occur within the box. Just as in rooms, the worst shape is a cube, since all the resonant peaks from each dimension will

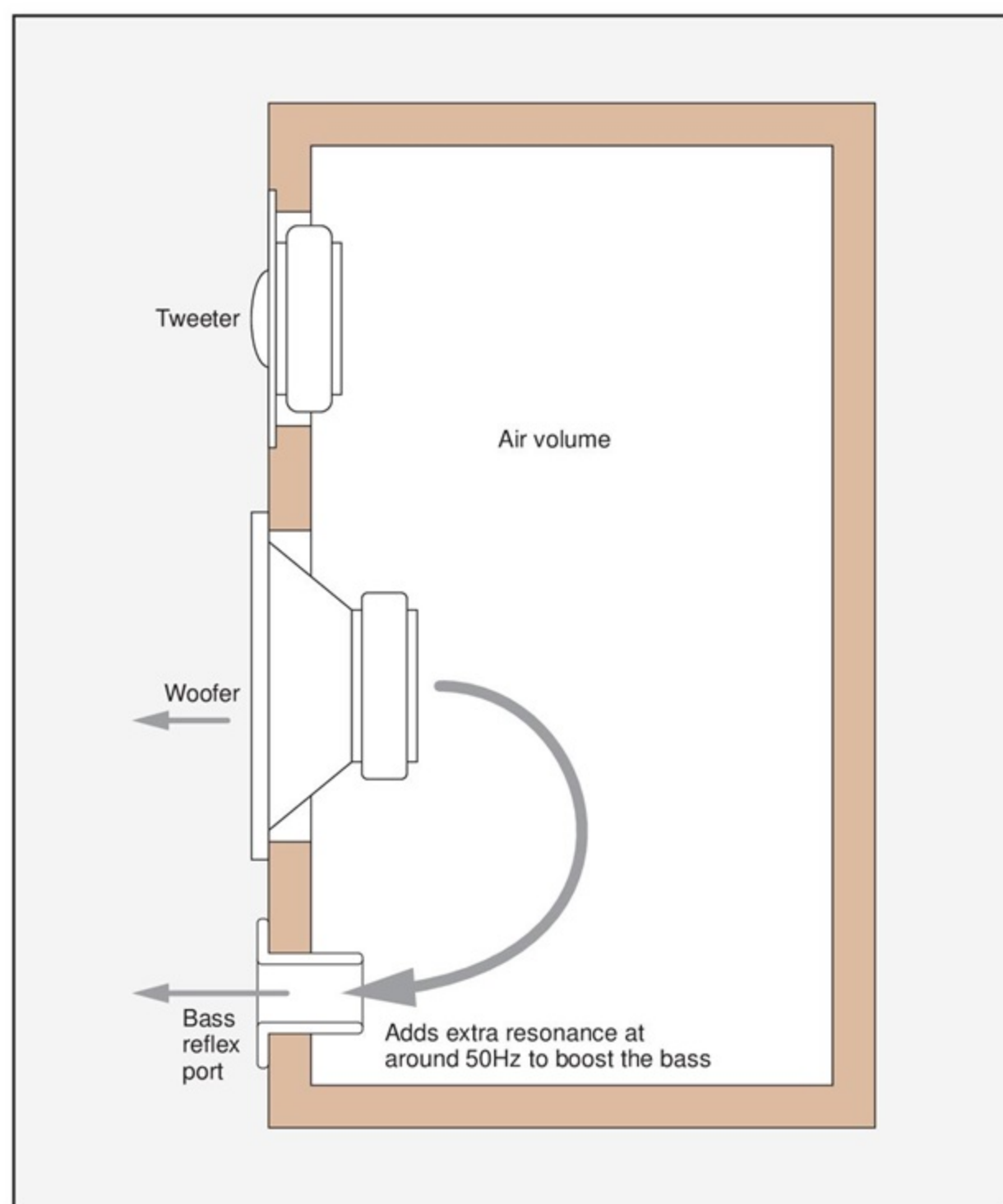


Fig.17. Reflex cabinets offer more bass but of poorer quality. They do allow higher resonance ($>45\text{Hz}$), lower Q (< 0.3) bass units to be used, which would be unsuitable for a closed box.

coincide. A more even distribution of peaks is obtained if each cabinet dimension (height, width, depth) is different. It's better still if dimensions corresponding to the golden ratio ($1:1.618\dots$). Plus, the cabinet should be deeper than it is width to minimise reflections from the rear. However the residual reflections still have to be attenuated, which is why most speaker boxes are lined with foam. This foam has to be of the open-cell soft type that absorbs water. In fact, specially optimised foams are available for acoustic applications.

I live in Wales, so I support the local economy by loosely filling my cabinets with sheep's wool, which has well-documented superior acoustic properties. Another benefit is that the wool makes the cabinet volume appear slightly bigger, lowering the resonant frequency by a few hertz. It does this by slowing down the sound velocity due to its high mass relative to air. The fibres also move about, adding to the moving mass of the system. KEF recently found that filling the cabinet with bags of activated charcoal enhanced these effects, making the cabinet appear a third bigger. You can overdo these techniques – it is possible to over-damp the cabinet resulting in inefficiency and bass loss.

Baffle boost effect

The frontal dimensions of the box are important because of their relationship

Tweeter diffraction

When the signal wavelength for high frequencies rises above (say) 1.5kHz the sound begins to diffract off the protruding edges of the front of the cabinet. This produces an interference pattern, which results in irregularities in the frequency response if the edges are sharp (to reduce this, see Fig.20). If the edges are rounded the diffraction is smooth. For the same reason it is necessary to flush mount tweeters into the speaker front panel – the baffle board. The sharp circular edge of the tweeter front plate will often give -6dB dips like a comb filter from 4kHz upwards if this is not done. Flush mounting tweeters into recesses on the baffle board is usually done with a router and template. For one-off builds I usually use two pieces of plywood, as shown in Fig.16.

Boom boxes

The sealed box speaker used to be common, but most modern designs are reflex systems, which means they have a hole in the box, normally with a tube attached, see Fig.17. This gives more bass at greater efficiency because it adds a Helmholtz resonance. This can be easily demonstrated by tapping a plastic soft drink bottle and holding the open top to the ear and a 'boom' will be heard. By reducing the size of the vent and extending its length with the hand it is possible to reduce the frequency of the resonance.

to the wavelength of the reproduced sound. Where the width of the box approaches the wavelength of the sound, the output of the system changes from omni-directional to directional, boosting the output when measured in front of the driver, on its radiating axis. This boost in output is often called the 'baffle step', and typically occurs at around 300Hz . It is undesirable in a good Hi-Fi speaker and it can be corrected with a shallow low-pass filter, a technique called 'step response equalisation'.

Reflex enclosures are good for selling speakers because they go louder and can use higher resonance units. However, I think they are less accurate than sealed boxes because they continue radiating bass after the note has finished. Also, they have a fourth-order, much sharper roll-off rate and a twice as high rate-of-change of phase (sometimes called group delay). Recent evidence has emerged that the ear can hear high group delay at low frequencies. Film and animation dubbing mixers have complained it is difficult to cut sound accurately to bangs and explosions with reflex speakers. Another problem is the coloured mid-range sound that can come through the reflex tube. For this reason I usually put the vents at the back of the cabinet. Another advantage of a sealed cabinet speaker is it is easier to integrate it with sub-woofers. A sixth-order crossover would be needed with a reflex design, which has massive group delay just where it isn't wanted.

Why modern speakers aren't as good as old ones

An effective technique to damp cone resonances is to paint the cone with a soft /plasticised PVA resin, such as Plastiflex P1200 (a bookbinding adhesive). This is called 'doping'; it gives a glossy 'wet' look to the cone. However, it is difficult to get this resin to stick to plastic cones. KEF used to put an intermediate coating of Bostik 4141 on the back to help the Plastiflex stick and then applied a second coat of Plastiflex. The front of the cone had only one coat of Plastiflex, and this sometimes comes off around the dust cap region.

Doping is not done much today because the speaker becomes subjectively much quieter, which is not allowed in today's decibel-oriented commercial world. It is also labour intensive, generally being brushed on by hand, which in turn causes variations between drivers. When I worked at Castle Acoustics in 1990, we automated the process applying a measured amount and spinning the cone. It seems only Falcon, Spondor and ATC are still doping drivers, which is a pity because it removes most of that 'cupped-hands, shouty' quality that tells you that you are listening to a loudspeaker.

The same loss-of-craft trend applies to cabinets. In good quality 1970s and 80s designs it was normal to apply half-inch-thick bituminous damping pads to insides of the panels, a horrid job involving tacky Aquaseal No.5 roofing glue. This reduced the coloured sound coming from the cabinet (the enclosure walls have resonant modes as well). The LS3/5A design specifies damping



Fig.18. Doping bass-mid units with a high hysteresis visco-elastic damping layer reduces the magnitude of break-up modes. The coating can be seen on the rear of this B110A cone.

pads on a box made from 12mm birch plywood with hardwood beech battens along each internal edge. The panel sizes were selected so that the resonances didn't coincide. Modern loudspeaker enclosures are made from MDF because it is easy to machine and looks good for sales. It does not sound as good because it rings badly and is difficult to damp because it is stiff and heavy. The home constructor is not constrained by such modern commercial pressures, so go ahead and damp your cabinets and dope your cones. I will show how this



Fig.19. Damping speaker panels with car body damping pads reduces ringing. This is the inside of a KEF 104ab cabinet. (In my lecture room demos, stolen from Lauri Fincham's lectures, are two bits of plywood – one with damping, one without. When hit with a beater stick one rings, the other emits a dull thud.)

is done later when we assemble our own LS3/5A-style cabinet.

The original and best

After a halt in production of over a decade, manufacture of the venerable, 40-year-old LS3/5A recommenced in 2015 at Falcon Acoustics, and they

have even brought the production of the original KEF drive units in-house. The founder of Falcon Acoustics, Malcolm Jones is still involved. I have met him a few times over the years and I can vouch for his engineering honesty. He does not hold with Hi-Fi snake-oil sales tactics. Unfortunately, a new pair



Fig.20. LS3/5A baffle board. The felt strips around the tweeter reduce diffraction glitches from the edge of the grill frame. Unlike most speakers, the LS3/5A works better with the grille in place. A 6.5kHz notch appears when it is removed.



Fig.21. Rear of an LS3/5A baffle board showing crossover. This was mounted on top of the tweeter magnet using a 3/8-inch thick felt pad to stop rattles. I was worried about the magnet affecting the coils, but I couldn't measure any difference.

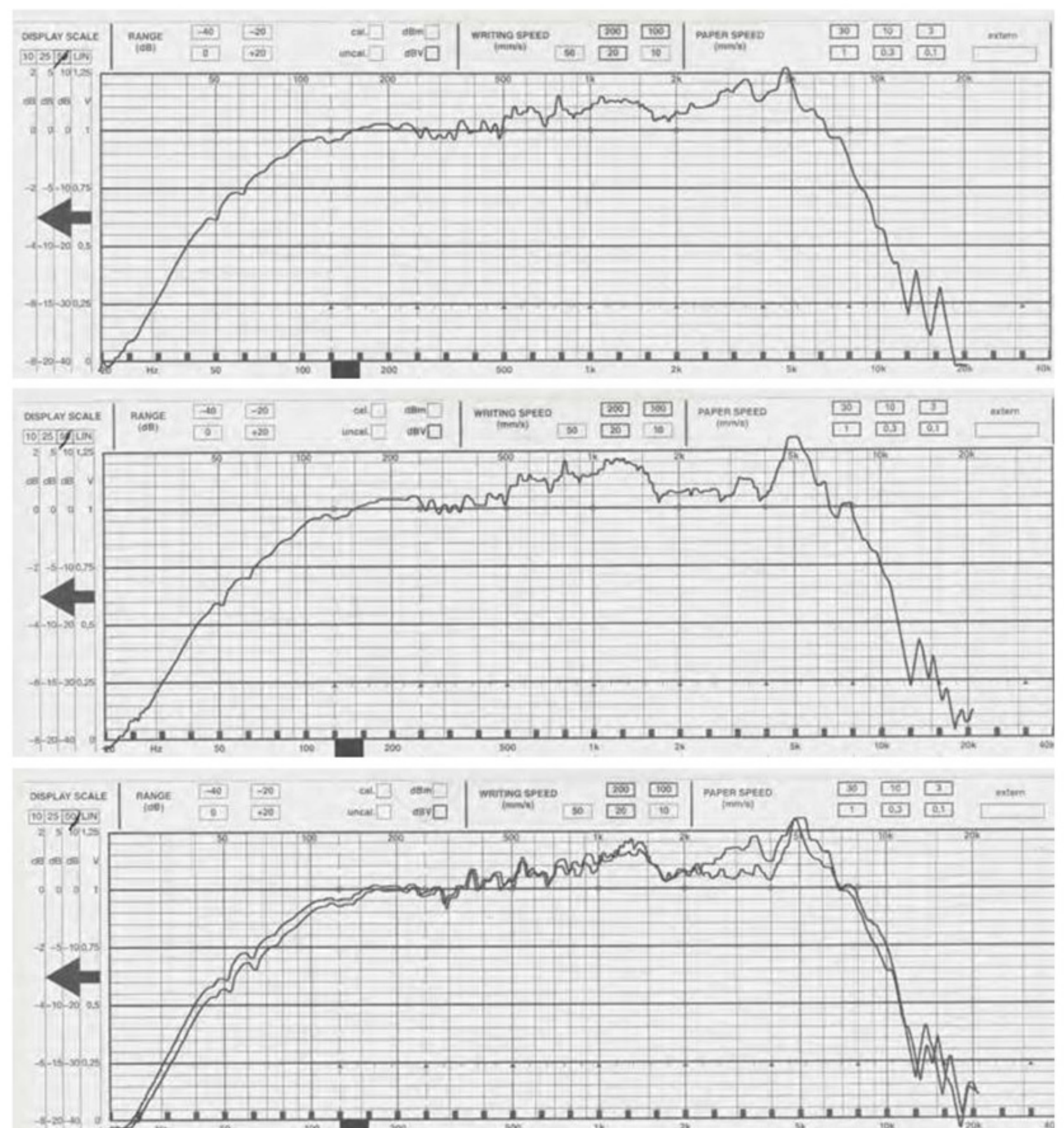


Fig.22. Comparison of front (top curve) vs rear (middle curve) mounting of bass unit in an LS3/5A. The curve is rougher for rear mount but it improves the phase alignment at crossover. Both curves are shown for comparison on the lower trace.

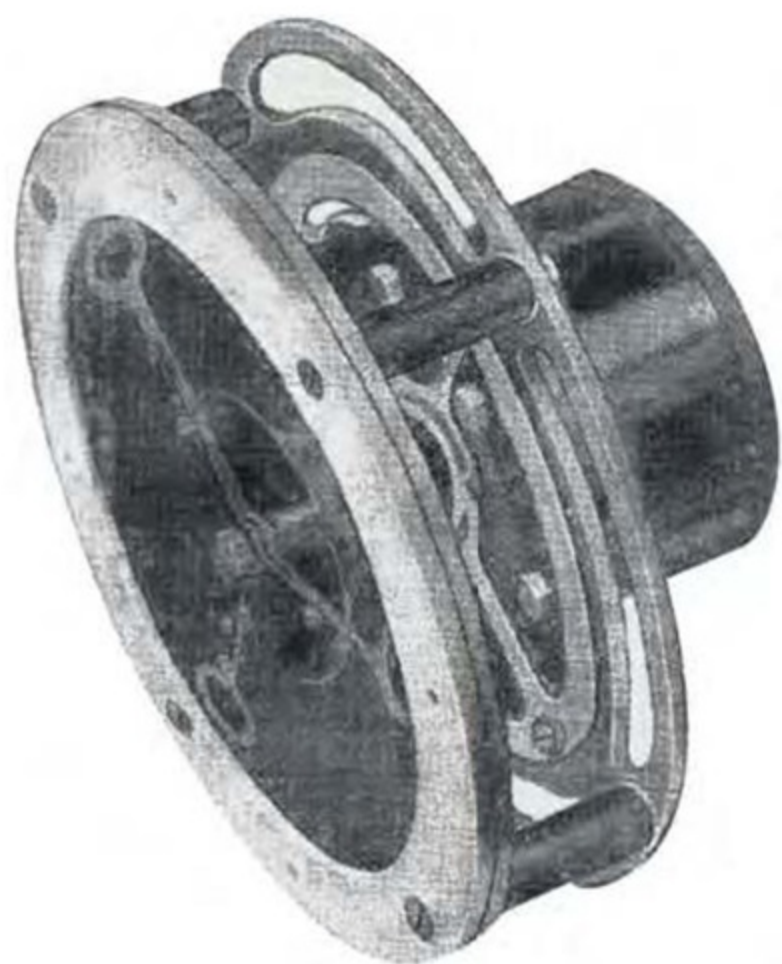


Fig.23. Driver for Goodmans 'infinite baffle' speaker – the first commercial closed-box speaker, launched in 1940.

of LS3/5As cost around £2300 today, up from around £150 when they first came out in 1975 – speaker inflation is nearly double that of the rest of the economy!

This looks even more expensive because the relative price of silicon-based electronic items has fallen greatly in real-terms. The cost of electro-mechanical parts, which form the basis of hand-built loudspeakers, has followed general commodity inflation so Moore's Law doesn't apply. There is also the 'eBay retro-fashion inflation effect' of the type that has boosted the

price of analogue drum machines and synthesisers. On the other hand, it is this new enthusiasm for good old analogue equipment that has now made it profitable to reintroduce these classic designs. Falcon sell the drive units, crossovers and most parts, so it is possible to build your own LS3/5As for around £850.00. To be clear, the licencing terms from the BBC preclude them from offering 'complete kits', but they will sell you all the parts you need, separately.

At one time, technicians at the BBC used to be able to buy kits. An uncle of mine built a pair, called the 'Chartwell Symphony'. They were quickly rescued from the charity shop when he died. I've also built quite a few myself over the last 30 years. It can be seen that by speaker standards, the internal construction of a typical LS3/5A is quite complex, as shown in Fig.21. Unusually, the bass unit is mounted *behind* the baffle board. Usually it is recommended to mount the drivers from the front to avoid cavity resonance effects, although it is still possible to get rear cavity effects with thick front baffles. Fig.22 shows there is a measurable deterioration in frequency response, but this is dealt with in the crossover. I suspect this was done to get the tweeter and woofer as close together as possible. Otherwise their frames would have overlapped.

A little history

In the 1960s there were only a couple of successful commercial mini-monitors, the Goodmans Maxim and the Celestion Ditton 10 (Fig.2). The Maxim was designed by veteran speaker designers Ted Jordan and Lauri Fincham. Goodmans had pioneered woofers for sealed-box bass cabinets and had advertised 'infinite baffle' speakers in the April 1940 issue of *Wireless World* (Fig.23). The Maxim four-inch woofer used the Alnico magnet Ted Jordan had designed for the 8-inch full-range Axiette drive unit in 1962. The Maxim unit defined the design requirements of the first proper mini-woofer to work successfully in a small sealed-box. This is illustrated in Fig.24. An original Maxim bass unit is shown in Fig.25. The BBC initially evaluated the Maxim and found it to be the best, but not quite good enough. It was possibly let down by its cone tweeter (see Fig.26). The 1965 report, (<https://bbc.in/2Ghzn5s>) provides objective relief from the new-age subjectivism of today's Hi-Fi press.

From this, the BBC R&D department's work led to the creation of the famous BBC LS3/5A mini-monitor in 1975. This is covered in the RD 1976/29 report (<https://bbc.in/2y33SYJ>). The BBC selected the B110 woofer and T27 tweeter designed by Malcom Jones at KEF. These were state-of-the-art

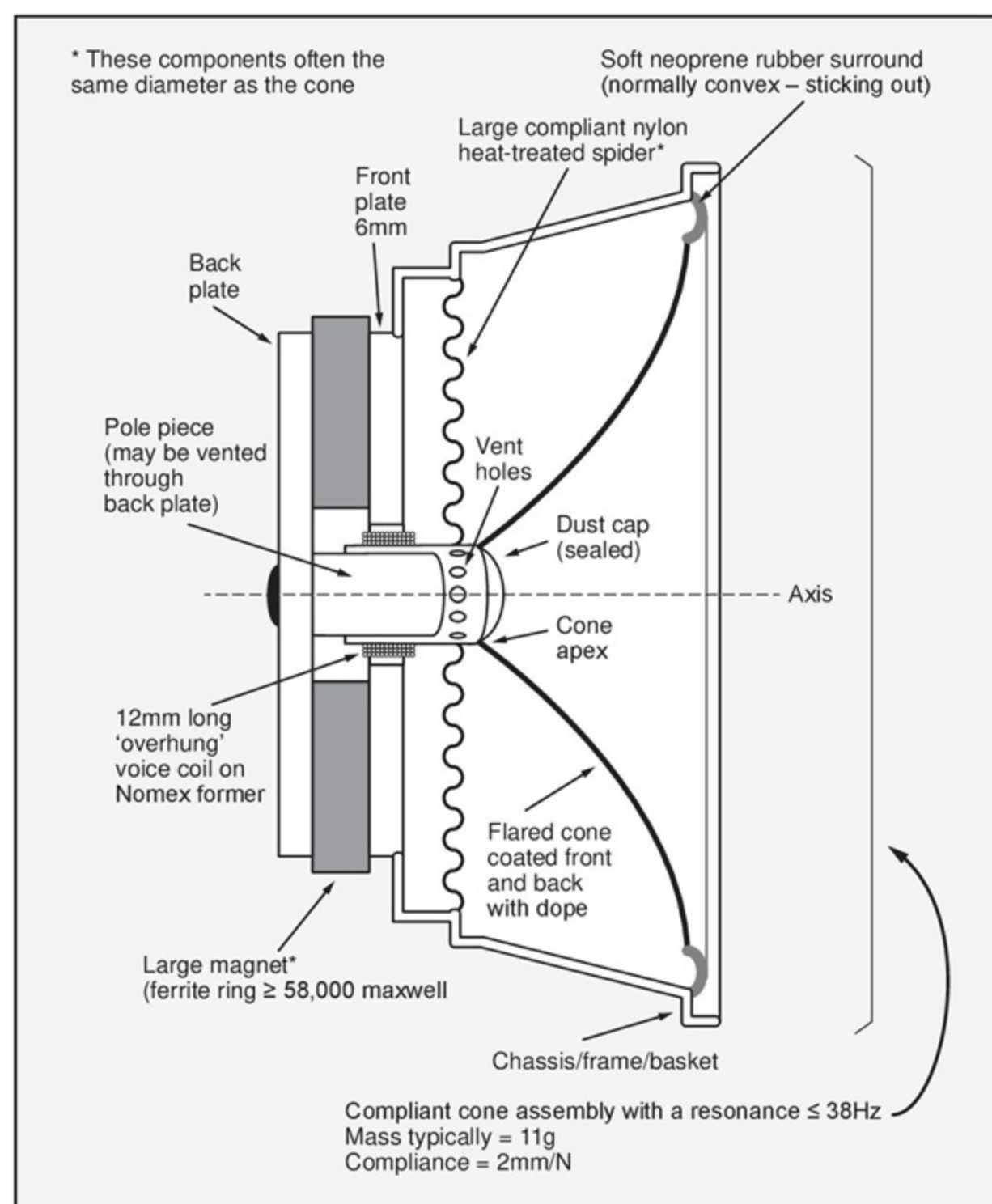


Fig.24. Generic bass-mid unit construction suitable for a mini-monitor. Note relatively large spider and magnet. Also note the long over-hung voice coil.



Fig.25. The first proper mini-monitor bass-mid unit used in the 1965 Goodmans Maxim. This had a latex-impregnated fabric roll surround to get flexibility. Later production changed to rubber. I once made my own similar surround for a woofer with lint and Copydex latex glue.



Fig.29. Front/rear view of KEF T27 tweeter.

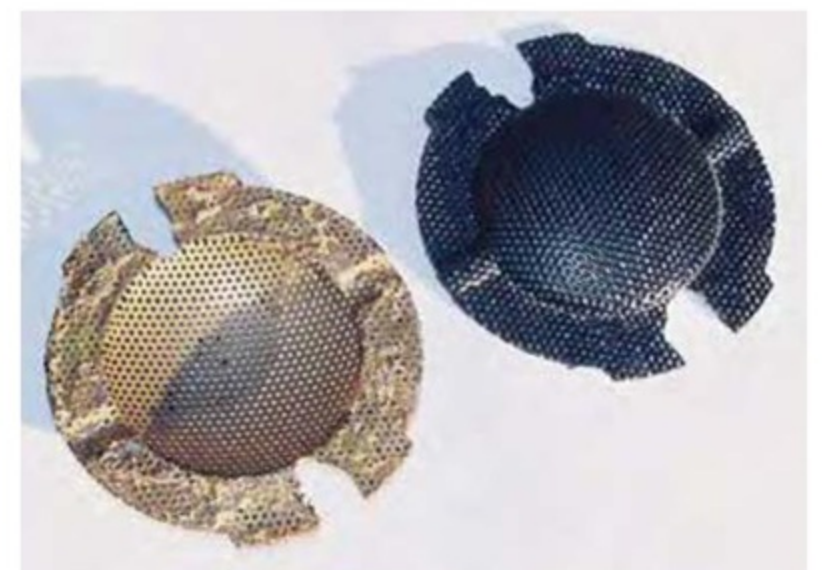


Fig.30. T27 diaphragm protection grille.



Fig.27. A B110A bass unit from KEF.



Fig.28. B110A diaphragm assembly. Note holes in the Nomex voice-coil to prevent pressure build-up under the dustcap (a common cause of distortion).

Fig31. The T27 had a cigarette filter placed in a cavity in the pole piece to absorb the rear radiation. KEF had made their own speaker system using these drive units called the Coda Mk1 to compete with the Ditton 10. This did not fully realise the potential of the drive units, having a simple four element second-order crossover and chipboard cabinet.

Nest month

In *Part 2* next month, we will have a thorough look at LS3/5A crossovers and start to consider activation and driver choices.

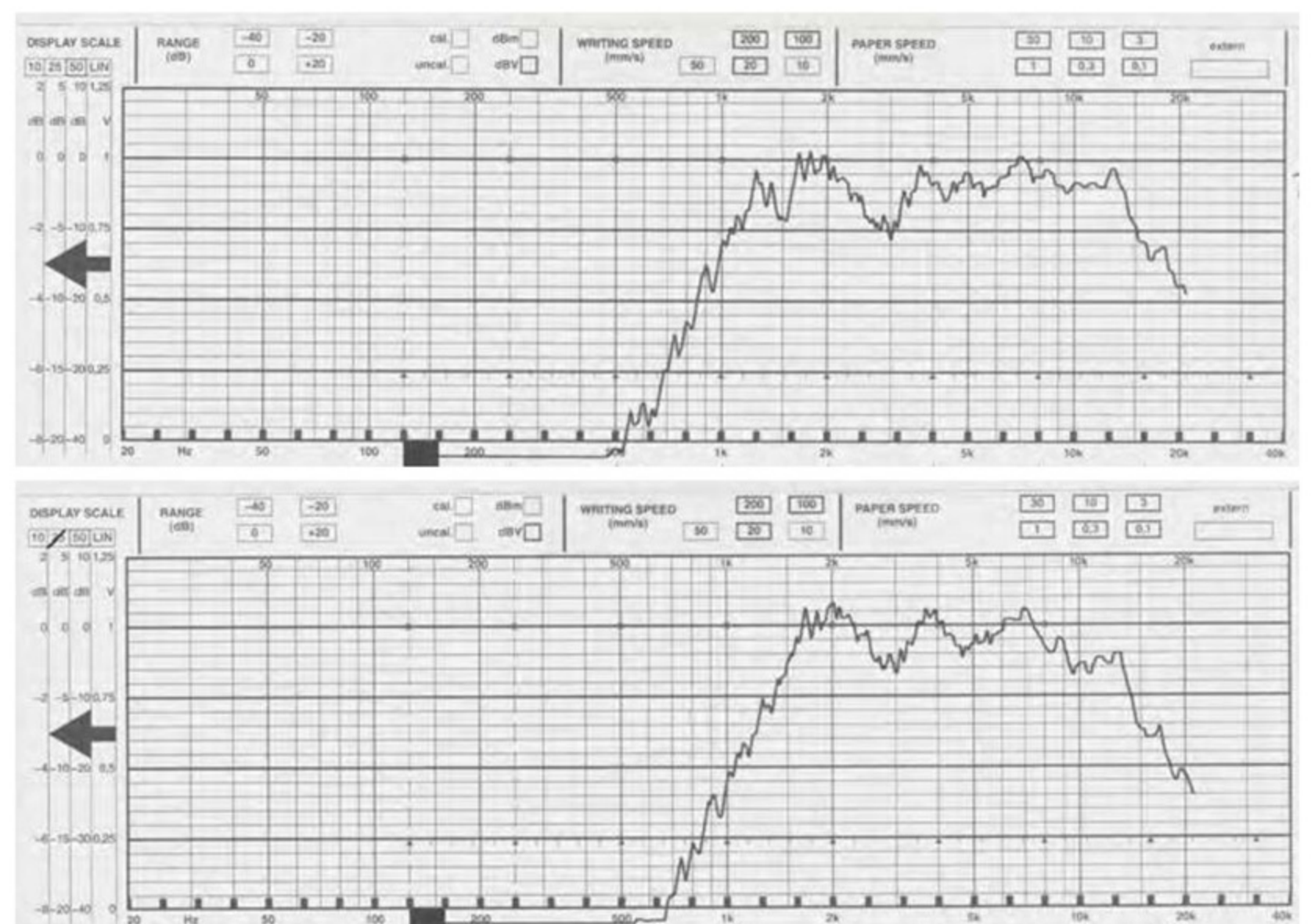


Fig.31. Effect of grille on the T27 frequency response (connected with no crossover filter). (Top) without grille and (bottom) with grille, lifting the response over 9 to 13kHz and providing a useful smoothing effect.

Practically Speaking

Hands-on techniques for turning ideas into projects by Max Maxfield

Three indispensable low-cost, low-tech tools

There are certain topics that electronic engineers like to talk about obsessively. If you really want to initiate a conversation, for example, a great opening gambit is to ask, 'What tools do you recommend for a beginner?' If you are feeling reckless, you might also ask, 'What is the minimum set of tools you need to get by?' At this point, you can step back and leave the sprocket (the collective noun for a group of engineers) to fight it out.

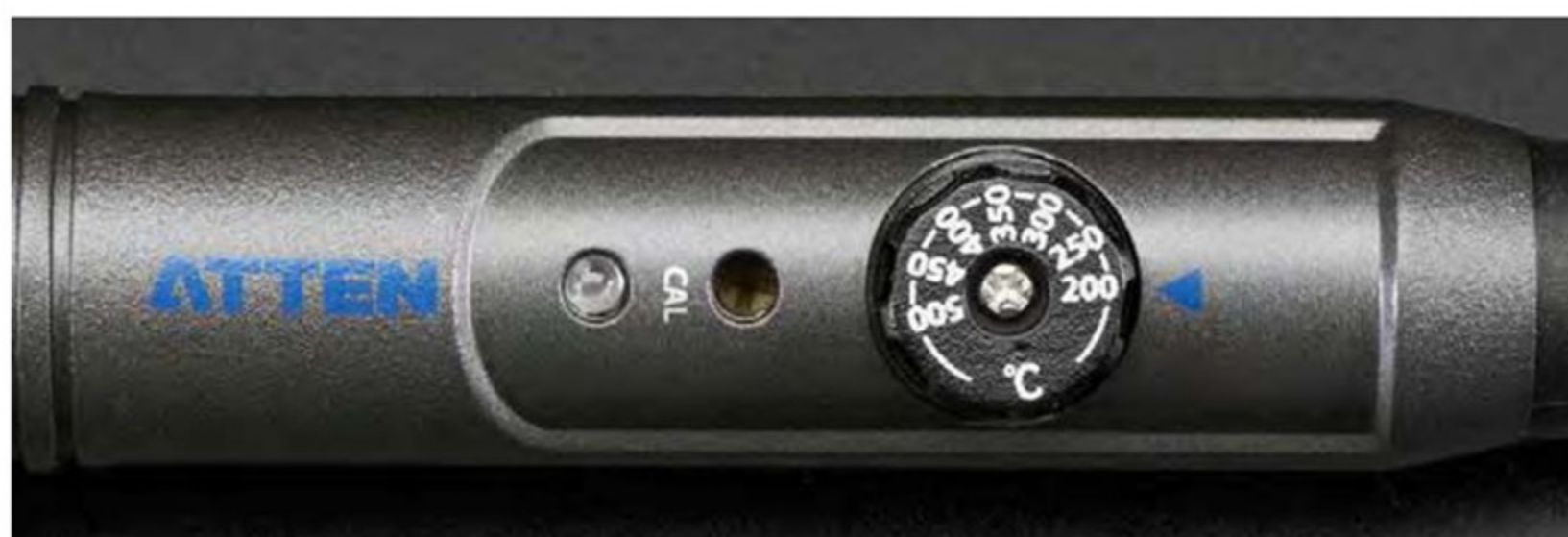
Strippers and screwdrivers

A good set of wire-strippers is a wonderful tool to have, for example, but an experienced engineer can use wire cutters to great effect (let's not get started on the relative merits of semi-flush, flush, and full-flush cutting edges). And, of course, we can debate the myriad aspects of screwdrivers, pliers, and similar tools until the cows come home.

Soldering irons

It probably goes without saying that one 'must have' is a soldering iron. You can spend a fortune here, if you're not careful, but you also have to make sure you don't opt for a 'bargain' that fails to cut the mustard (I never metaphor I didn't like). Some time ago, I dropped my existing soldering station and damaged it beyond repair. I purchased a new one from somewhere, but – even though it wasn't cheap – it turned out to be a pain in the nether regions to use.

Fortunately, my chum Rick Curl, who spends much of each day soldering, undertook a survey for his company. As part of this, Rick evaluated a bunch of irons, eventually determining that the best all-rounder in terms of quality, cost, and capabilities, was the Atten 50-watt Soldering Iron (SA-50). I ordered one from Adafruit for \$29.95 (<https://bit.ly/2DWkVPR>) and I have to say that I've been delighted with the result. This is so much better than my previous soldering station... but, of course I'm based in the US, so that is a 110V tool. For those of you over in the UK and



There are many good soldering irons out there, and I'm certainly not claiming to have used them all, but my friend Rick Curl has looked at plenty and we both recommend the inexpensive Atten SA-50. Make sure you get the right version for your region – the above is for US 110V, but UK/Europe-friendly 230V versions are also available.

Europe, Somerset Solders are offering a 230V version of the SA-50 for £24.95, see: <http://bit.ly/2Jxh0M1>

Multimeters

If you start to become serious about electronics, then at some stage you need to consider splashing the cash for an oscilloscope and/or logic analyser. I personally prefer to have these as standalone units, but you can get some tasty and affordable devices that display data on your PC screen using USB or on your smartphone/

tablet using Bluetooth or Wi-Fi. However, before you go decide to take the plunge, one indispensable tool for checking voltage current, and resistance is a multimeter. These come in all shapes, sizes, and price points, but you really don't have to spend much to get something useful. For example, the cheap-and-cheerful multimeter I keep in my backpack cost only about \$3 Australian Dollars. I've had it for a couple of years now and it works like a charm. Budget meters are now so cheap that if you find one you like, get two or three.



Construction is not just about the latest hi-tech digital gizmos – craft ('ice lolly') sticks, masking tape and good school (safe and washable) glue are truly indispensable aids!

Component testers

When I was first introduced to these little rascals about three years ago (<https://ubm.io/2UEttF0>), I couldn't believe my eyes. Costing only \$15 to \$20 on eBay, these comprise a small circuit board carrying a microcontroller, ancillary components, a zero-insertion force (ZIF socket), and a little LCD display.

All you have to do is connect a 9V battery, pop your component into the ZIF, and press the start button. The tester then evaluates your component (resistor, capacitor, inductor, diode, transistor), identifies what it is and which pins are which, and describes any relevant information (resistance, capacitance, inductance...).

I tell you, I'm so enamored of these little scamps that I wrote an article

asking if anyone wanted to join me in building an Arduino-based equivalent (<https://bit.ly/2UXwwHH>).

Hot glue is your friend

Although I was aware of their existence, I never actually used a hot glue gun until a couple of years ago. Now I'm kicking myself for all the time I wasted doing things that took ages that could have been handled in seconds with a dab of hot glue.

One thing you have to be careful about is to not use hot glue on circuits that are under power. I did so once with very unfortunate results (<https://bit.ly/2IlqmLE>). At first, I thought that the hot glue in its liquid state had caused a short circuit, but I measured it with my multimeter and that wasn't the issue. Eventually

I came to the conclusion that the hot glue had driven my active tri-colored LED into thermal overload.

Three indispensable tools

In reality, I use all of the tools mentioned above, but where are those 'indispensable

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Teach-In 9 – Get Testing!

This series of articles provides a broad-based introduction to choosing and using a wide range of test gear, how to get the best out of each item and the pitfalls to avoid. It provides hints and tips on using, and – just as importantly – interpreting the results that you get. The series deals with familiar test gear as well as equipment designed for more specialised applications.

The articles have been designed to have the broadest possible appeal and are applicable to all branches of electronics. The series crosses the boundaries of analogue and digital electronics with applications that span the full range of electronics – from a single-stage transistor amplifier to the most sophisticated microcontroller system. There really is something for everyone!

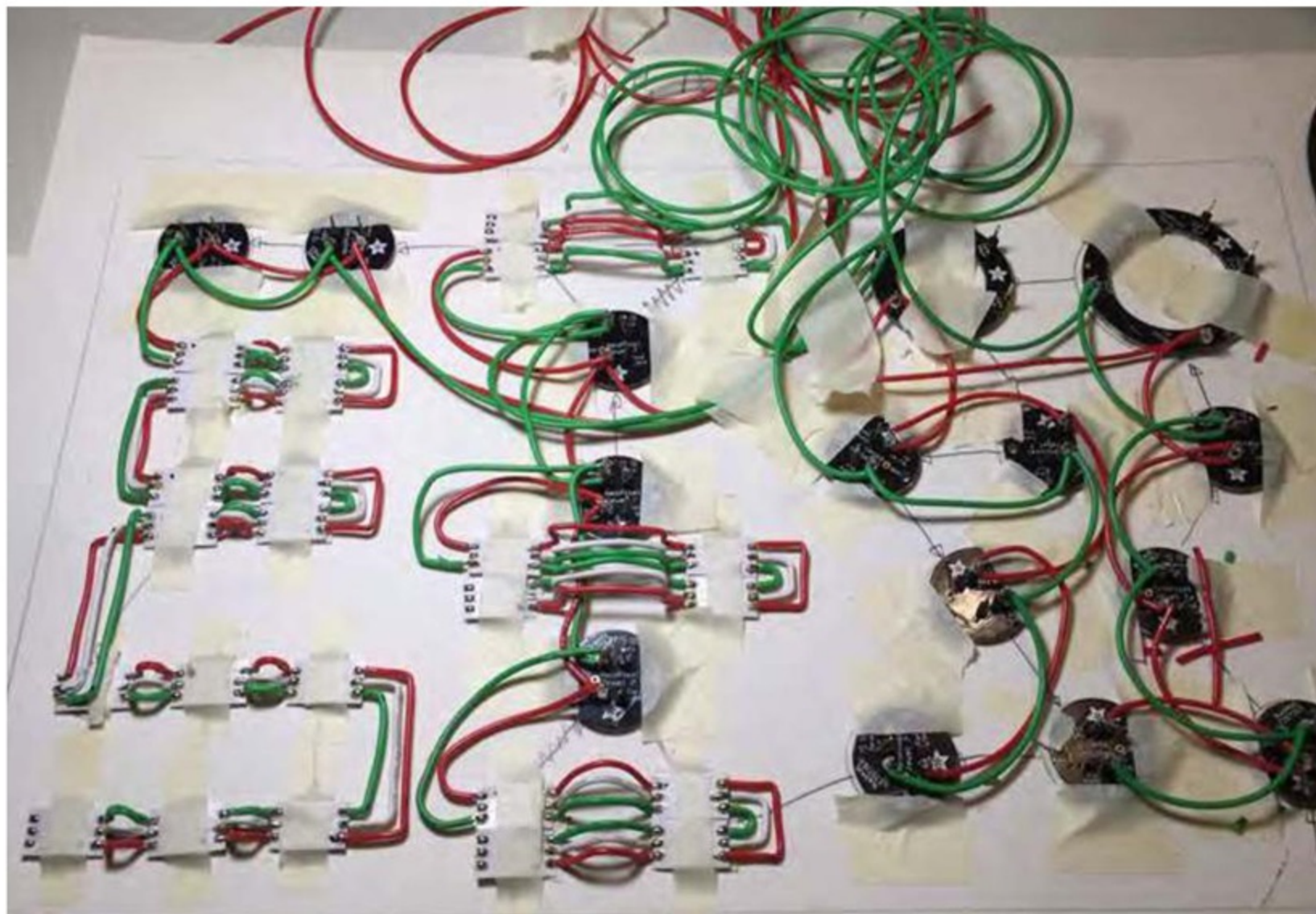
Each part includes a simple but useful practical test gear project that will build into a handy gadget that will either extend the features, ranges and usability of an existing item of test equipment or that will serve as a stand-alone instrument. We've kept the cost of these projects as low as possible, and most of them can be built for less than £10 (including components, enclosure and circuit board).

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Using masking tape to hold LEDs on a cardboard wiring harness template.

low-cost tools' I promised at the start? Well, here are three low-tech offerings that I never want to be without: Elmer's School Glue (available from amazon.co.uk, but other brands are good), decorator's masking tape and wooden 'ice lolly'/craft sticks. Honestly, when I'm setting things up at the start of a new project, these three items are 'front and center' on the table.

I use the masking tape for all sorts of things, but especially holding components in place while I'm soldering them to a circuit board. Another example was assembling my *Awesome Audio Reactive Artifact*; I used it to hold all of my tri-colored LEDs in position on a cardboard mockup while I arranged the wiring harness (<https://bit.ly/2KGz7lj>).



Using school glue and lolly sticks to make mini-clamps (back).



Using school glue and lolly sticks to make mini-clamps (front).

Meanwhile, the Elmer's Glue and craft sticks find myriad uses. In the case of my *Inamorata Prognostication Engine*, for example, I used them to fashion mini-clamps to hold my tri-colored LEDs in place during alignment and attachment (<https://bit.ly/2P8wrLK>).

So, what are your favorite tools, including any unconventional low-tech offerings? I'm always interested in this sort of stuff, and you can email me as shown below.

Max Maxfield is editor-in-chief at **EEWeb.com** – the go-to site for users of electronic design tools and all askers of electronic questions.

Comments or questions? Email Max at: max@CliveMaxfield.com

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Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 8: Dice Prediction game and Mini MKC Clock



This month, we will discuss two projects. The first is a simple *Dice Prediction Game*, (DPG) which is based on the *Electronic Dice* hardware covered in *Part 6* (see Fig.1). The second project is a small, yet highly-accurate *Mini MKC Clock* (see Fig.2) that uses a very nice little display.

We'll learn how to use VT100 escape codes, which date back over 40 years to the VT100 video terminal produced by DEC (Digital Equipment Corporation). They were initially designed to allow on-screen formatting of text and information, and later included colour effects, some of which are incorporated into the *DPG* to display the score and some basic game instructions (see Fig.3). The `SETTICK` command will also be discussed; this allows the dice LEDs to be

continually updated while simultaneously playing sound effects.

Many projects (such as the *Mini MKC Clock*) need a dedicated output display; so we will be showing you how easy it is to connect up a mini colour LCD display module. The one we'll be using this month has an IPS (in-plane switching) screen, which gives it a wider viewing angle, and a brighter and clearer image than regular LCDs. It is a nice, compact module with a pixel

resolution of 160×80 ; more than enough for displaying the time and date.

The obvious question for this clock is how does the *MKC* know what the time is? The answer is it doesn't; we will need to connect it to a real-time clock (RTC) module. The good news is that MMBASIC makes the whole process of building the *Mini MKC Clock* really simple.

As always with these projects, components such as the IPS screen and RTC module are inexpensive; both are individually available online at micromite.org, or as a kit of parts.

Project 1: Dice Prediction Game

The purpose of creating the *DPG* is to demonstrate how to incorporate many of the topics covered in the *Make it with Micromite* series. It uses hardware and software to show how ideas and concepts work in practice to create a total solution. It is not meant to be the next big thing in gaming – however, there is nothing stopping you from using it as a basis for

your own customised game(s). Over the coming months we will expand the game as we learn new topics; it will evolve and change over time. The game's code (**DicePredictionGameV1.txt**) is available from the September 2019 page of the *PE* website. You could download it straight away, load it into your Micromite (using `AUTOSAVE`, `Paste`, and `Ctrl-z`) and immediately start playing the game; however, I recommend you work through the topics in the articles first, as that is the best way to learn about the many features of MMBASIC.

The *DPG* uses the *Electronic Dice* hardware that was covered in *Part 6*, but with the addition of a piezo sounder, allowing it to make some sounds (as discussed in *Part 7*). Do note that the *Electronic Dice* software needs to be changed to accommodate displaying dice patterns on the LEDs while simultaneously playing sounds, which leads us neatly to a new command.

SETTICK command

The `SETTICK` command enables us to set up a periodic interrupt (or 'tick'), which effectively means that an interrupt subroutine is automatically called at regular intervals. The command syntax is:

```
SETTICK period, target, nbr
```

Here, *period* is the time (in ms) between calls to the interrupt SUB, and *target* is the name of the interrupt SUB that is called. Four separate 'ticks' are available, each being referenced by a number (*nbr* (1, 2, 3, or 4)). By the way, the `SETTICK` interrupt is disabled (switched off) by setting the *period* to a value of 0 (zero).

Questions? Please email Phil at:
contactus@micromite.org

Micromite code

The code in this article is available for download from the *PE* website.

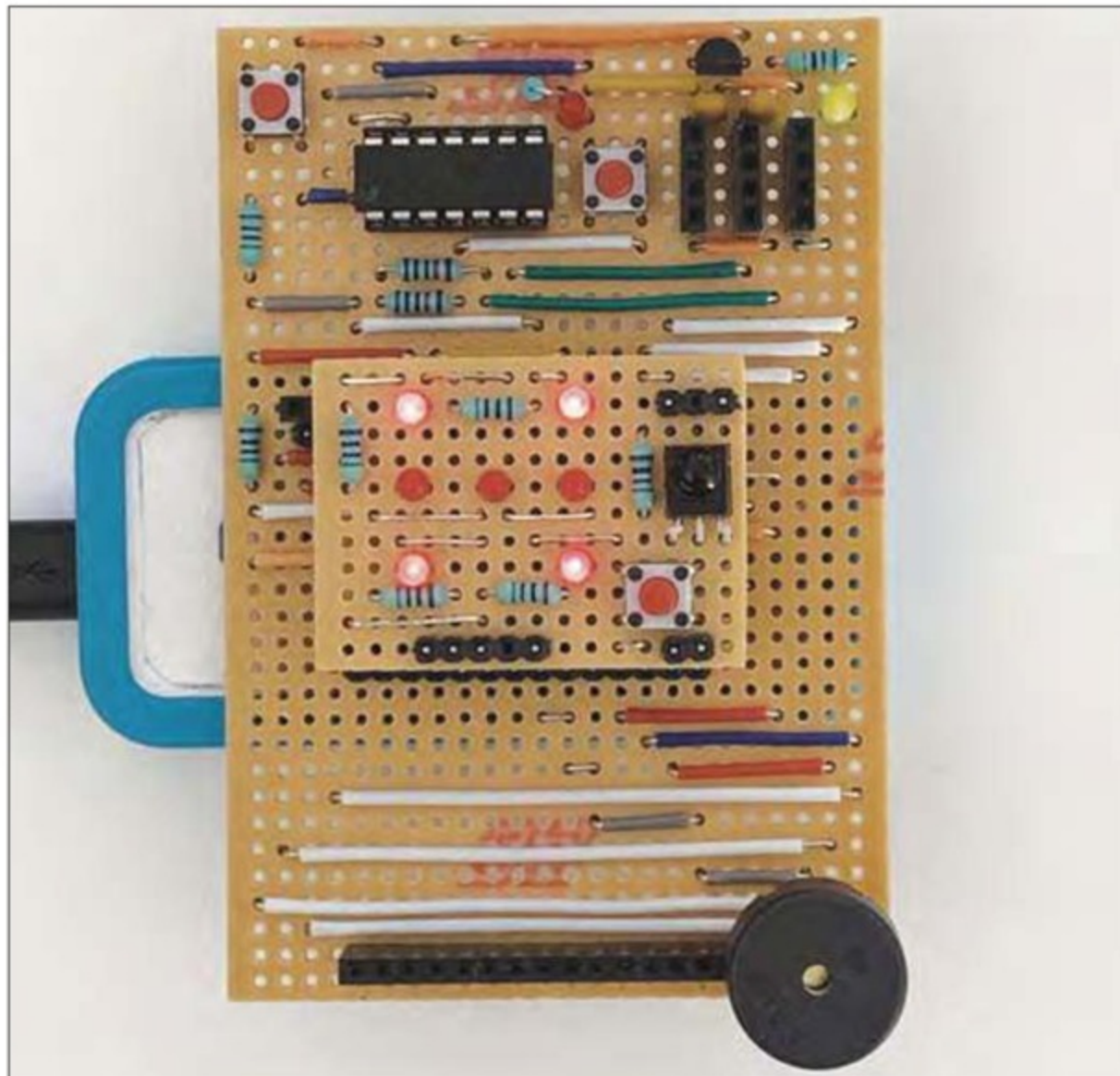


Fig.1. The *Dice Prediction Game (DPG)* is based on the *Electronic Dice* module (Part 6). It has a piezo sounder for audible notifications, uses the console screen to display the score and instructions, and the console keyboard for entering your guess.

This process can be likened to MMBASIC allowing things to be done ‘in the background’ (not quite multi-tasking, but similar). In the game, we will use `SETTICK` to continually update the dot pairs that ultimately form the displayed dice pattern (see Fig.3 and 4 in Part 6).

To demonstrate `SETTICK`, and also prepare for the game, simply plug the *Electronic Dice* module into your *DM/MKC* and connect this to your computer. Also connect a piezo sounder to J12 (the 20-way connector) on the *DM* between Pin 22 and Pin 26 (see Fig.4). Then launch TeraTerm (or Terminal/Screen for MacOS) and start a new program by typing `NEW` at the command prompt.

SETTICK example

First, we will use the `SETTICK` command to display dice pattern ‘6’ on the LEDs, totally independently of the flow of the main-program. This is best demonstrated by example, so enter the following code into the EDITor. Code comments aren’t included because we will discuss the code below. However, do note that the second line needs to be commented out for now (ie, the `SETTICK` command will not run due to the single apostrophe preceding it, which tells MMBASIC the line is a comment and not code).

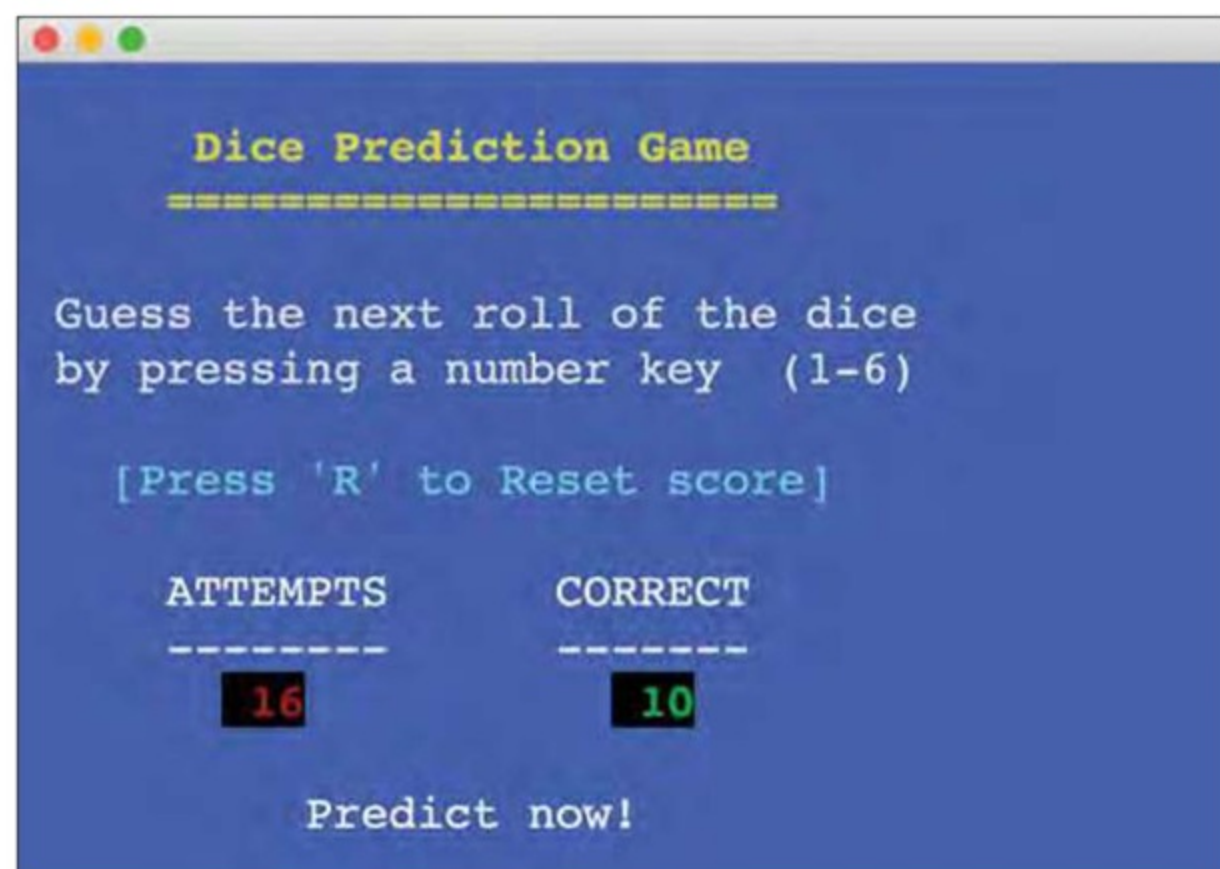


Fig.3. How the *DPG* looks on the console screen.

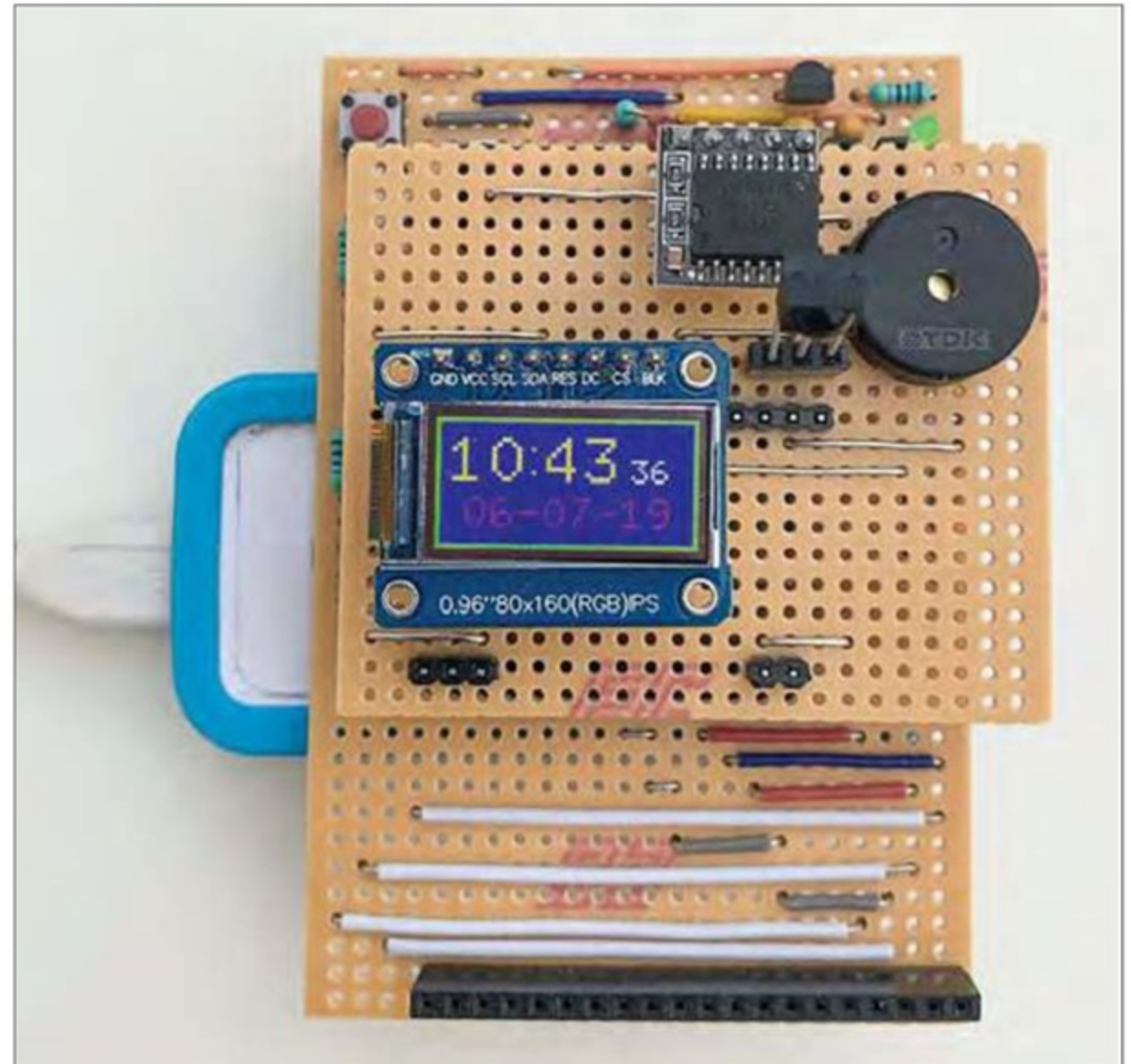


Fig.2. The *Mini MKC Clock* is based on a versatile plug-in module that incorporates a mini IPS display, RTC module, infrared receiver and a piezo sounder.

```

SETPIN 4,DOUT:SETPIN 5,DOUT:SETPIN 6,DOUT
`SETTICK 1,LEDdisp,3
s1=&b100 : s2=&b010 : s3=&b011

` main-program
DO
  PRINT Time$
  PAUSE 1000
LOOP

` subroutines
SUB LEDdisp
  SELECT CASE LEDctr
    CASE 0: PORT(4,3) = s1
    CASE 1: PORT(4,3) = s2
    CASE 2: PORT(4,3) = s3
  END SELECT
  LEDctr = LEDctr + 1
  IF LEDctr > 2 THEN LEDctr = 0
END SUB

```

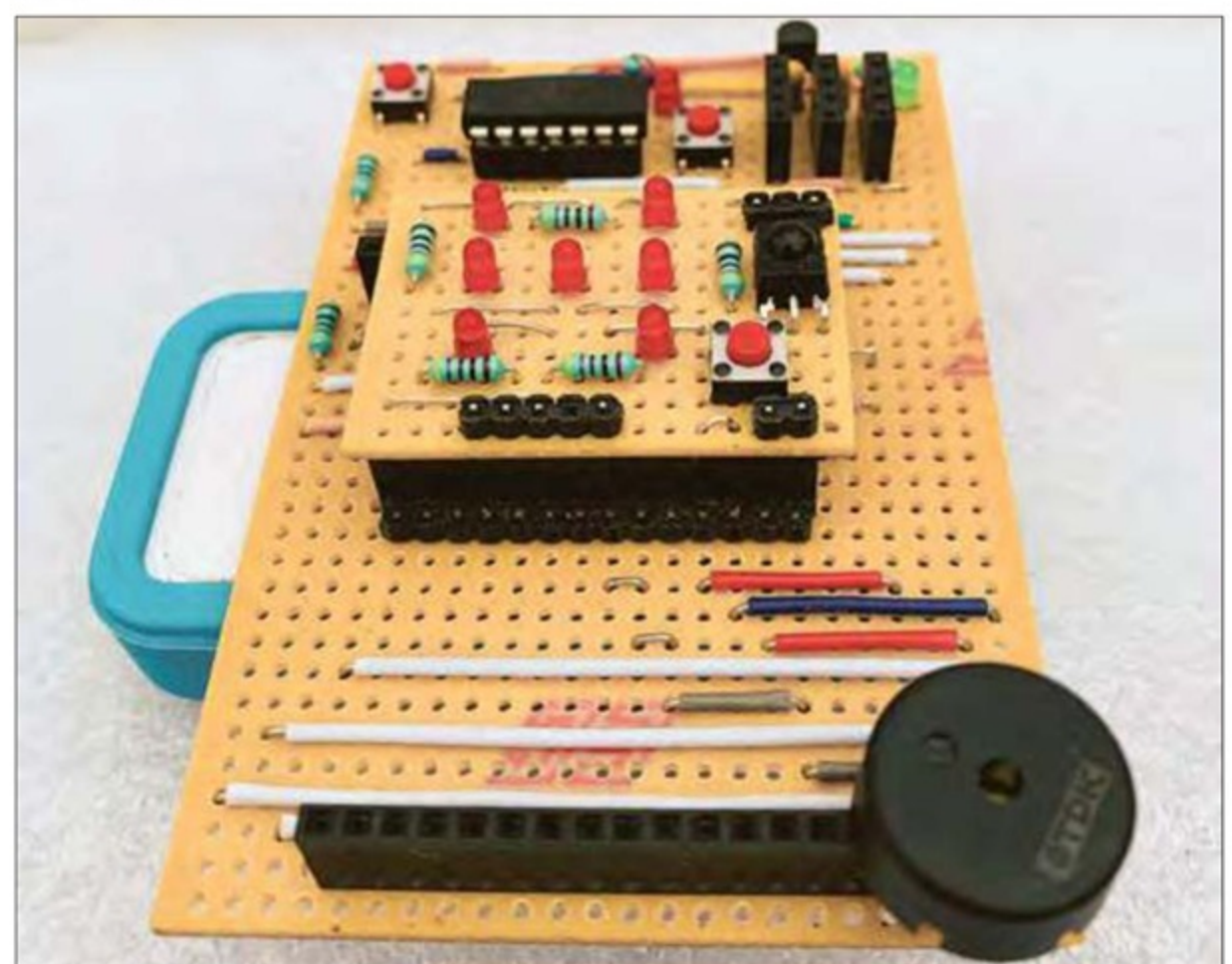


Fig.4. For the *DPG*, the *Electronic Dice* module is inserted as normal. A piezo sounder is connected via the 20-way connector between pin 22 and pin 26 (use a breadboard and jumper wires if required).

If you RUN the above program, not much will appear to be happening. All you should see is a timer-looking counter on the console screen counting up at one second intervals (and there should be nothing displayed on any of the dice LEDs). Not very exciting, but it will demonstrate SETTICK nicely as we will soon see.

The program may look complex, but all it is doing is initially setting up the three LED pins (as outputs), then loading the three 'dot-pair' variables (s1, s2, and s3) with the binary values that represent the dice-pattern '6' (when they are rapidly and sequentially outputted to the *Electronic Dice* module). Then the code enters a DO/LOOP, which continually displays Time\$ at one second intervals. This is all that the main-program is doing (and nothing else) – it repeats over and over. The important point to note here is that main-program has nothing to do with driving any of the LEDs.

Now stop the program (Ctrl-c) and use the EDITor to remove the single apostrophe from the start of the second line so that the SETTICK command will be executed. Re-run the code again (F2) and this time observe what happens on the LEDs. If the code above was entered correctly then you will see the LEDs displaying the dice pattern '6' (if not, check your code is correct, and also ensure the dice hardware module is inserted correctly).

What the SETTICK command does in the above program, is set up an interrupt tick (number 3) at 1ms intervals, diverting to run the code in the interrupt SUB LEDdisp. The interrupt SUB code simply sends a 3-digit binary value (s1, or s2, or s3) onto pins 4, 5, and 6 with the PORT command (as covered in *Part 6*); the choice being dependant upon by the value of variable LEDctr. The counter variable (LEDctr) is used to count up (initially from 0) each time this interrupt SUB is called, and when it reaches a count of 3 (ie, >2), then it is reset back to 0. In other words, LEDctr can only ever have a value of 0, or 1, or 2 – and nothing else. This allows us to use its value to sequentially and rapidly cycle through the three LED dot-pairs s1, s2, and s3 (by using SELECT CASE), which then forms the overall LED dice pattern. Remember, we use persistence of vision to fool our brain into seeing a 'solid' dice pattern on the LEDs, and that is why we need to call the interrupt SUB quickly – every 1ms – otherwise we would see flicker.

Let's now examine what happens if the interrupt SUB is called too slowly for the persistence of vision effect to work. We can do this by increasing the period parameter in the SETTICK command. Stop the program (Ctrl-c), and change the SETTICK period value to 100 (or

higher), then RUN the program once again (F2). The main-program flow has not been changed in any way, but you will now see the three dot-pairs displayed (slowly), in turn. Set the period back to the original value of 1 and the dice pattern '6' will once again be seen. By the way, this exercise also demonstrates the usefulness of being able to quickly run/test/edit/re-run code on the Micromite – something that is unique to Micromite, and will always prove to be extremely useful during code development.

I hope this has demonstrated how SETTICK can be used to effectively perform 'background' tasks. We now have the ability for the main-program to play tunes (and to perform other tasks), while simultaneously displaying a dice-pattern on the LEDs. If we were to change the values of s1, s2, and s3 in main-program, then this would automatically result in a different dice pattern being displayed. This is the technique that is used in the DPG.

Using VT100 escape codes

Previously, we have used MMBASIC's PRINT command to display alphanumeric on the console screen. For example, PRINT "Hello" will display Hello on the console. Note that within the PRINT command, we are not defining the location of where it is displayed on the console since the output is displayed at the current cursor position. After using the above PRINT example, the current cursor position moves to the start of the next line (this is because MMBASIC also sends 'line feed' and 'carriage return' instructions after displaying the word Hello). However, if we were to use PRINT "Hello"; instead (note the semicolon at the end), then the current cursor position would be located immediately after the word Hello, and not at the start of the next line (this is because the semicolon suppresses the line feed and carriage return). This rudimentary cursor position control is limiting, especially if we have several things we wish to lay out nicely on the console screen. And what if we wanted to update something located in a fixed position (such as a score for a game)? This is where VT100 escape codes come into play; they allow total control of the cursor position, as well as control over other types of formatting, including font colours.

The 'console screen' we are using (ie, TeraTerm), is a VT100-compatible application, so by sending VT100 escape codes, we are able to format the display prior to using the PRINT command. The formatting we will discuss below will include cursor position, and font colour, but the same technique applies to implementing other types of VT100 formatting.

Please note that the Micromite can connect to many different types of colour LCD modules (as we shall soon see with the IPS screen); and these allow the Micromite to perform some very powerful graphical features without needing to use escape codes. However, before we look at MMBASICs ability to drive LCD modules, it is worth understanding how to do some simple formatting on the console screen using VT100 escape codes.

It's important to understand that VT100 escape codes are a feature of the VT100 Terminal standard, and are not a feature of the Micromite. We are simply showing here how you can send them to affect what is displayed by the subsequent PRINT command. Also note that different console applications (ie, TeraTerm for Windows, or Terminal/Screen for MacOS) vary in their ability to recognise some of the formatting escape codes. That said, most are capable of correctly interpreting the escape codes used here.

If you search online for 'VT100 escape codes' you will see many lists of what we are about to discuss. Personally, I like to use the list at the following website: www.termsys.demon.co.uk/vtansi.htm and I will refer to it in the discussion below. Do read the notes at the top of the webpage (immediately above *Device Status* heading).

Scrolling through the list from the above website, you'll see lots of things containing <ESC> followed by a few more characters such as [{COUNT}A (scroll down to the second item in the *Cursor Control* section). To the left you'll see a very brief description of the action it performs; in this example, Cursor Up. Underneath each <ESC> is a slightly longer description.

So if we were to send the escape Code: <Esc>[{COUNT}A to the console, then the cursor will move up the relevant number of lines (defined by the value in {COUNT}). But how to send the escape code? Well, as with most things in MMBASIC, this is really easy. All we do is use PRINT CHR\$(27)+"..."; replacing '...' with the characters shown in the list (and with any required values). So, sticking with the above example to move the cursor position up one line, we would simply use: PRINT CHR\$(27)+"[1A";

Breaking this down:

- PRINT simply sends the escape code to the console
- CHR\$(27) is the <ESC> element
- + adds on whatever follows in double quotes
- [1A is the specific code to move up {COUNT} lines for which we have supplied the value 1
- ; ensures the cursor remains in the correct position (rather than move down to the start of the next line).

- Important note: escape codes are case sensitive!

Now we know the concept of escape codes, and how to send them, let's start using some examples and see how they affect the PRINT command.

Cursor position

Start by entering the following new program (be sure to enter all semicolons, commas and single apostrophe as shown):

```
PRINT "Hello1";
PRINT "Hello2",
PRINT "Hello3"
PRINT "Hello4"
`PRINT CHR$(27)+"[1A";
PRINT "Now Here!";
```

With the fifth line commented out, RUN the code and carefully look at the result on the console screen (see Fig.5a). The first PRINT line ends with a semicolon and this tells the console program (eg, TeraTerm) to leave the cursor at the current position (immediately after Hello1). This is why Hello2 is positioned immediately after Hello1 (remember that the PRINT uses the *current* cursor position). However, the second PRINT line ends with a comma and this informs the console program to position the cursor further along the same line at the next tab position. This is why Hello3 is spaced away from Hello2 (but all three are on the same line). The third PRINT line has neither a comma or semicolon at the end, so this instructs the console program to move the cursor to the start of the next line and hence Hello4 is on the next line down. The forth PRINT line also moves the cursor down hence Now Here! is on a new line too. I hope this all makes sense so far!

Now remove the single apostrophe from the start of the fifth line of code (which currently comments out the 'Cursor Up' escape code). Before you run it, think about what you expect to happen with the escape code we are using here (ie, move up 1 line). RUN it again and see if it results in what you expected (see Fig.5b).

In case it was different to what you thought, understand that Hello1, Hello2, and Hello3 all appear on the first line as before, and also that Hello4 is on the second line with the cursor then moved down to the third line (again, as before). However, the escape code will move the cursor back up one line to effectively where Hello4 is. Finally, Now Here! is printed at the current cursor position; ie, it overwrites Hello4.

To explore cursor positioning further, experiment with some of the other escape codes shown in the list under the *Cursor Control* section. In particular, try Cursor

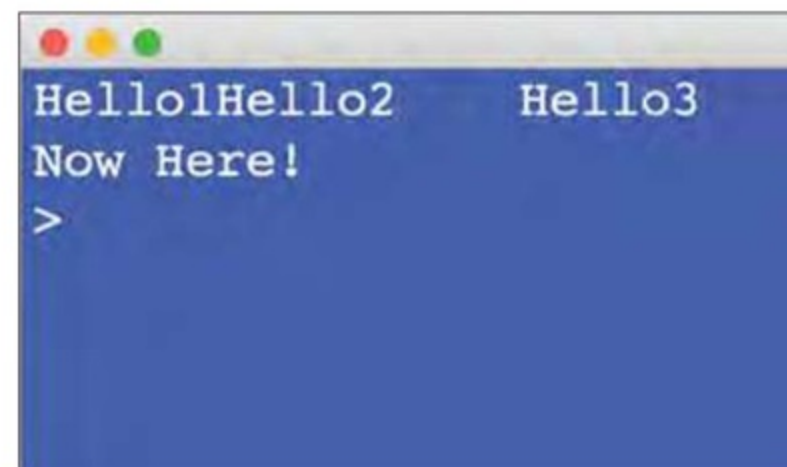
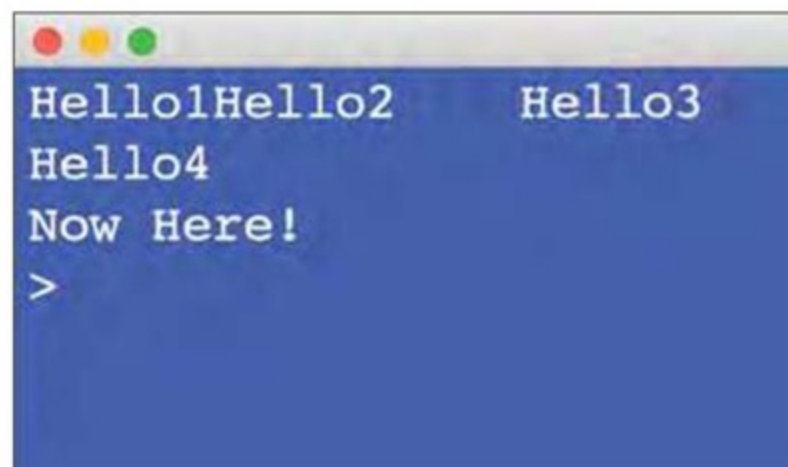


Fig.5. Cursor position escape code: a) (left) observed console output when using only PRINT commands, b) (right) exactly same PRINT commands, but with the inclusion of a single Cursor Up escape code.

Home – ie, <ESC>[{ROW};{COLUMN}H to move the cursor anywhere on screen (ie, use PRINT CHR\$(27)+"[10;20H";)

Font colour

Now that we have seen how to send escape codes, setting font colours should be relatively straightforward. At the escape code website, scroll down to *Set Display Attributes* to see what colours are available. *Foreground Colour* refers to the font colour.

Modify your existing code to become the following (add the highlighted lines and remove the previous *Cursor Up* escape code):

```
PRINT CHR$(27)+"[2J";
PRINT CHR$(27)+"[H";
PRINT CHR$(27)+"[33;41m";
PRINT "Hello1";
PRINT CHR$(27)+"[32;45m";
PRINT "Hello2",
PRINT CHR$(27)+"[46;31;4m";
PRINT "Hello3"
PRINT CHR$(27)+"[1;33;1;44m";
PRINT "Hello4"
PRINT CHR$(27)+"[1;32;2;40m";
PRINT "Now Here!";
`PRINT CHR$(27)+"[0m"
```

In the above program, the first line sends the escape code to clear the screen (found in the website's *Erasing Text* section). The second line positions the cursor at the top-left of the screen (the Home position). The other escape codes then control the Foreground Colour and Background Colour along with other attributes, such as Bright, Dim, and Underscore. Note that attributes remain in place until they are changed, or until they are reset (with <ESC>[0m). Indeed, the last line demonstrates Reset all attributes but for now, leave it commented out.

Once you have entered the above code, RUN it and observe the colours (see Fig.6). Refer to the website for confirmation of all Foreground Colour and Background Colour options. Now, at the command prompt, type something (such as PRINT TIMES) and you will see the colours remain as bright green underscored characters on a black

background. Next, use the EDITor to remove the single apostrophe (which will then activate the last Reset all attributes escape code). Now RUN the code again and you will see that the screen background has remained black, however, this time the command prompt is no longer green on black because Reset all attributes is now sent at the end of the program. Run the program one last time and now the screen background will be back to 'normal'.

The above examples have demonstrated just how easy it is to use VT100 escape codes. When used creatively, they can give some very impressive results. The lay out of the DPG screen (Fig.3) was created by using just a handful of these escape codes. Do take a look at how they are implemented in the code for the game; and feel free to modify them to suit your tastes.

Finally, it is well worth scrolling through the complete list of all the escape codes listed at the above website. If something interests you then why not try it out and see what happens – this is the best way to learn.

Running the Dice Prediction game

If you haven't already done so, download **DicePredictionGameV1.txt** from the September page of the PE website and load it into your Micromite using AUTOSAVE, Paste, and Ctrl-z (as discussed in Part 6). Then RUN the program (F2) and you should see the game appear on your console screen as shown in Fig.3. Don't forget to add a piezo sounder between Pin 26 and Pin 22 so that you hear the sound effects – you can do this via the 20-way connector (J12) on the DM, using a breadboard if necessary.

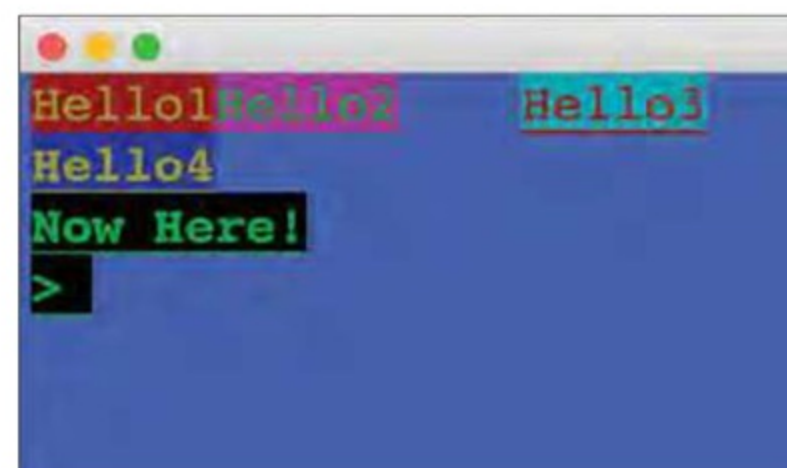


Fig.6. Result of using some simple font colour escape codes.

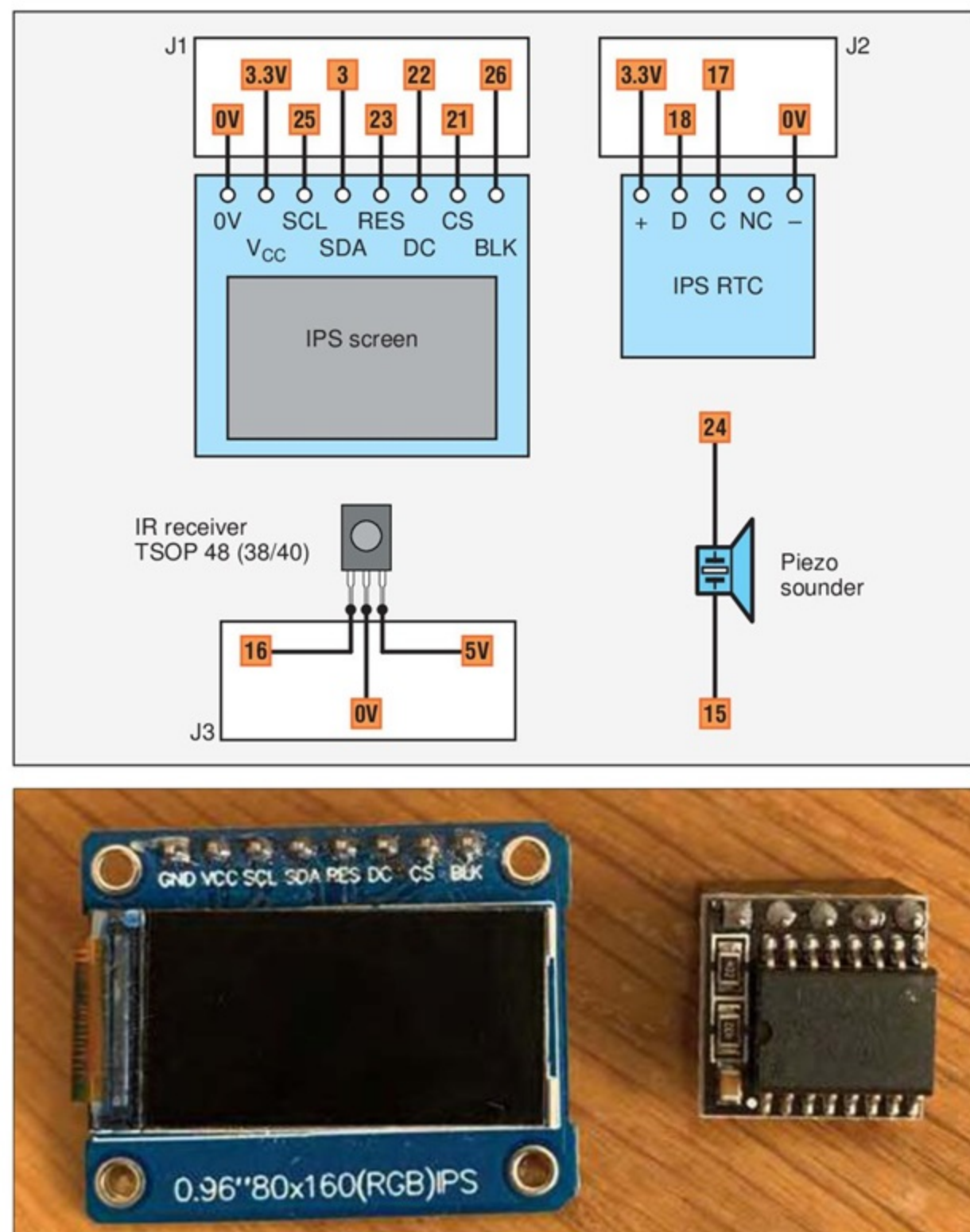


Fig.7. (Top) Circuit diagram for the *IPS Display Module (IDM)*; (below) the IPS display and RTC module.

Due to the size of the program, we will not take up valuable space by listing it here. However, do take a look at the code as you should recognise how all the commands are being used. The program contains comments throughout, so you should also be able to follow the flow of the game.

How to play

The game is simple to play. All you need to do is predict the next number that will be 'rolled' on the dice by pressing a number key (from 1 to 6) on the computer's keyboard. (Use the number keys above the QWERTY keys, not the numeric keypad.) Upon pressing a valid number, the dice will automatically be 'rolled' (and the 'spin' effect will appear on the LEDs). The dice will end up on a number, and if it matches your prediction, then a 'success' tune will play along with your score for 'CORRECT' guesses being incremented. Incorrect guesses will play a different tune. Every guess will increment the 'ATTEMPTS' counter to show you how many times you have played. Pressing the 'R' key will reset the game (set both scores to zero), and also play another tune.

This version of the game uses the console's screen and keyboard, so you cannot play it without having the *DM* connected. In addition, neither the Spin button, nor the IR remote transmitter functionality, are implemented. However, IR will be implemented in a future version of the code, with the IR remote transmitter replacing the console keyboard. If we were to add a dedicated LCD screen (to display the score), we could disconnect the *DM* and simply plug the *DPG* module directly into the *MKC* to create a standalone project.

The purpose of the game is to demonstrate many of the techniques that we are learning in these articles, and that is why it is worth looking through the program code line-by-line. It is not meant to be the latest in addictive masterpieces; however, I hope you have some fun with it! And please do experiment with the code – here are a few ideas to try out (and do at least try the last one!):

- Change the colours and layout of the game (ie, change escape code parameters)
- Add a 'spinning' sound effect – use the PWM command to enable and then stop the piezo from within SUB Spin
- Calculate the number of correct guesses as a percentage of the total attempts and display it on the console after each roll of dice – use escape codes followed by `PRINT INT((correct/attempts)*100) + "%"`
- Add your own musical tune and play it at power-up – add tune info as `Tune_PowerUp` DATA line(s), then use `RESTORE Tune_PowerUp` and `PlayTune` in the relevant place within the program
- Convert the *DPG* into a *Memory Game* – comment out `RANDOMIZE Timer`, and then press the reset button every time you want to play it. See how high you can score correctly – the higher the number, the better your memory!

If you wish to share your creations, or have any comments or ideas, then do drop me an email – it is always great to hear from you: contactus@micromite.org

Project 2: Mini MKC Clock

We are now going to briefly describe how to construct a very versatile plug-in *IPS Display Module (IDM)* that incorporates a mini IPS screen, RTC module, infrared receiver and a piezo sounder. Incidentally, these four hardware elements can be used as the basis for many different projects – so by using exactly the same hardware, but altering the program code, the *IDM* can be made to perform a wide variety of different tasks.

We will load a program on to the *IDM* which will create a simple, yet highly accurate *Mini MKC Clock*. The code will be explained in next month's article – we are just using it initially to confirm that the IPS Display module has been assembled correctly.

The circuit elements to be added to the *IDM* are shown in Fig.7. As with most Micromite-based projects, it is just a matter of connecting component 'legs' (and/or pins on a module) to the appropriate Micromite pins. Note that the IPS screen comes with header pins already soldered, and the RTC module comes with a socket. Therefore these two parts, along with the IR receiver, will have appropriately placed sockets/headers on the strip board allowing each item to be inserted, or removed, as required (see Fig.8). The piezo is the only component soldered directly onto the strip board.

The IPS screen has a total of eight pins (and is inserted into socket J1). From left to right:

- **GND** and **Vcc** supply the 3.3V.
- **SCL** and **SDA** are two SPI protocol pins and have to be connected to Micromite pin 25 (SPI Clock) and pin 3 (SPI Out) respectively.
- **RES**, **DC**, and **CS** are control signals and can be connected to any available I/O pin; for ease of strip board layout we will use pins 23, 22, and 21.
- **BLK** is the backlight control. Taking this low will 'switch off' the backlight; and left floating (or high) leaves the backlight switched on. By connecting BLK to a PWM pin we will be able to control the brightness of the backlight via software, therefore we will use Micromite pin 26 which is PWM channel 2A.

The RTC module has five connections (and is mounted onto pin header J2). From left to right:

- **+** is the 3.3V supply
- **D** and **C** are the two I²C protocol pins and have to be connected to Micromite pin 18 (I²C Data) and pin 17 (I²C Clock).
- **NC** is no connection
- **0V** is the supply.

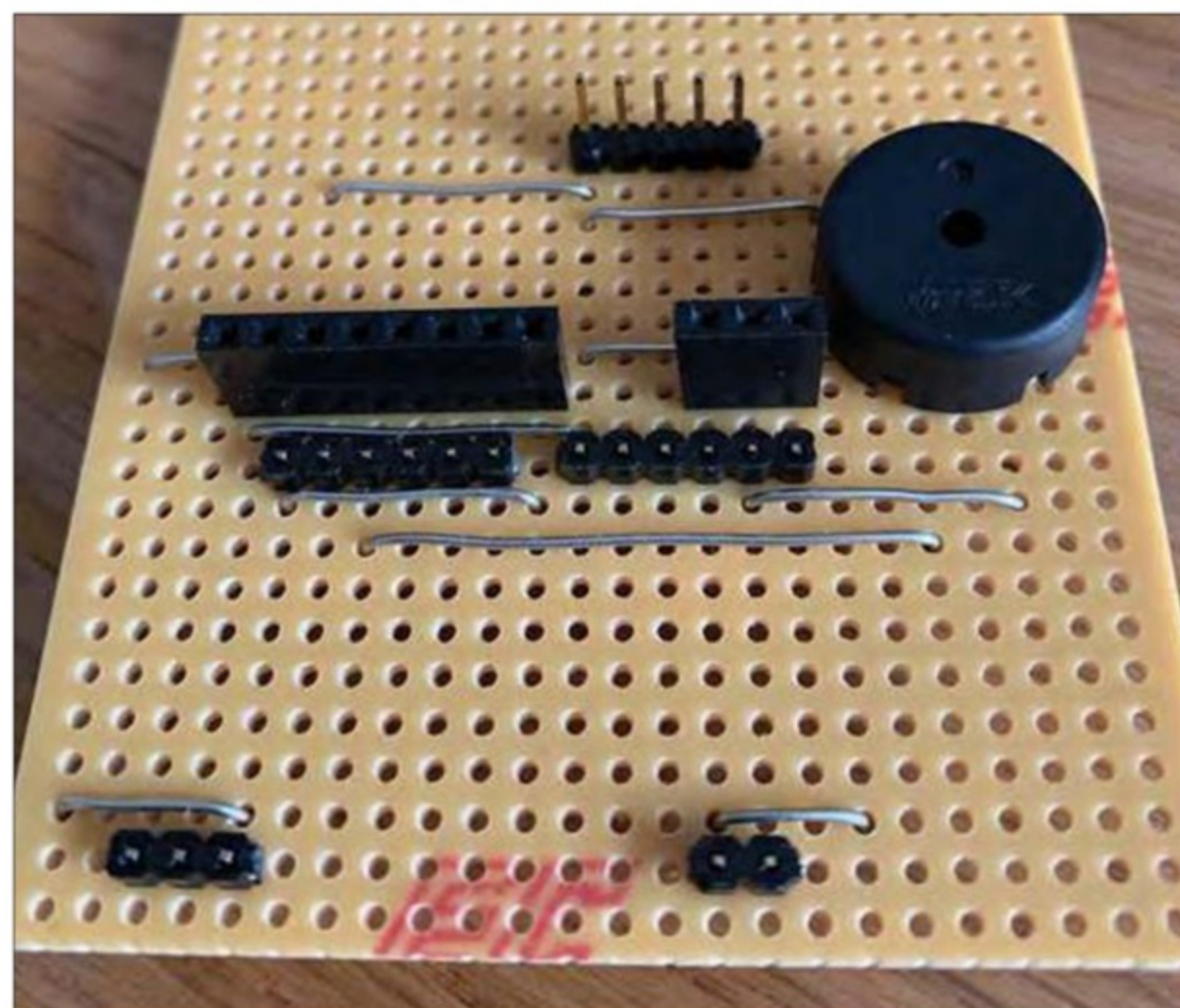
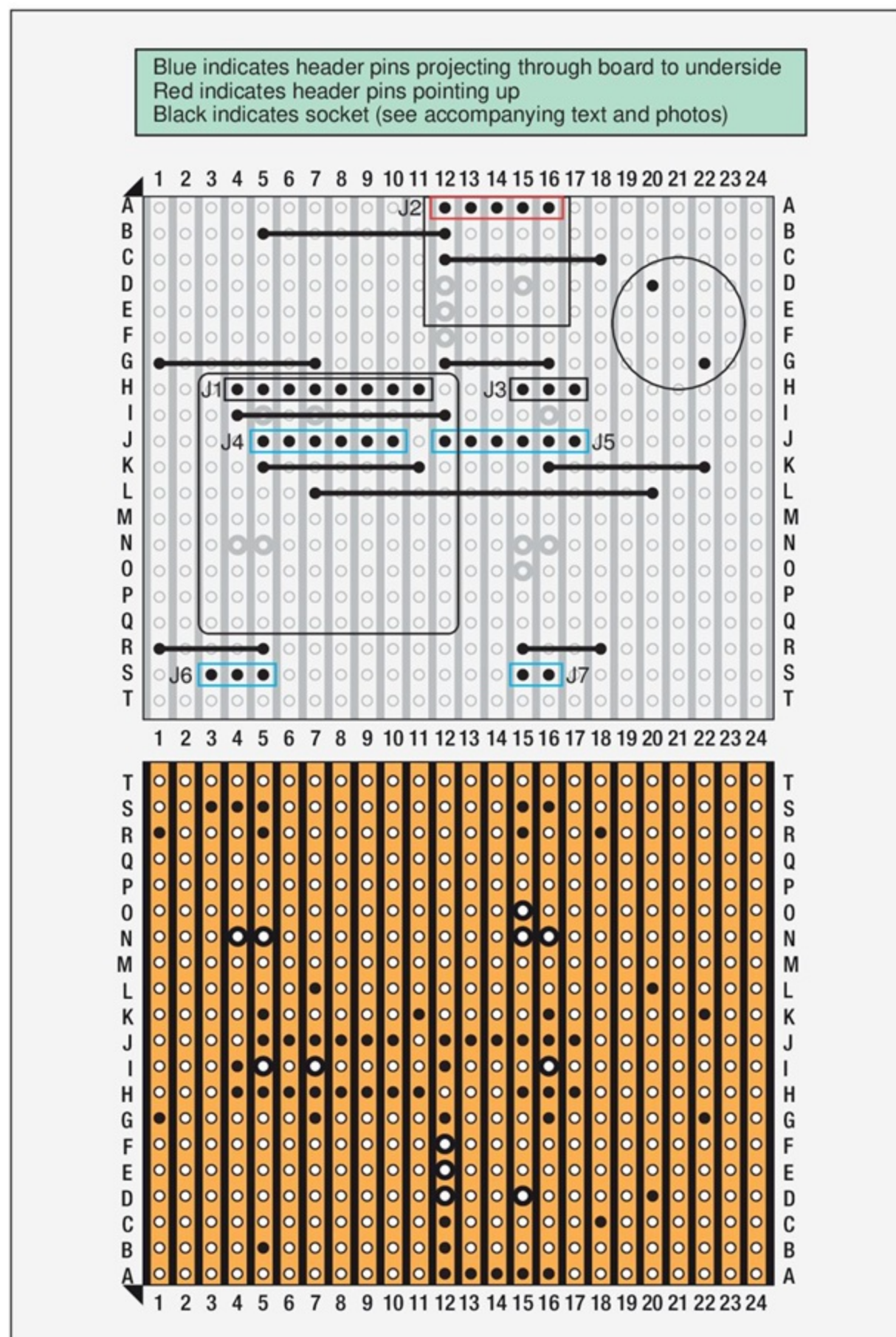


Fig.8. (Top) Stripboard layout for the *IDM* on which the *Mini MKC Clock* is based; (Below) assembled *IDM*.

There is a small button battery on the underside of the RTC, so take care when handling this module. The battery keeps the RTC ticking over whenever main power is removed from the supply pins.

The IR receiver needs a 5V supply, and its output has to be connected to Micromite pin 16 (as we saw in *Part 6*). It is inserted into J3. The piezo sounder will be connected to PWM channel 2B which is on pin 24. However, the other piezo pin will not be connected to 0V; instead, it is connected to Micromite pin 15. This allows us to use `SETPIN 15, DOUT`

to enable the sound (as it will then be a 0V), and use `SETPIN 15, OFF` to disable the sound (as pin 15 will then be floating).

Assembly of the IDM

The *IDM* is assembled onto a piece of stripboard 24 tracks wide, with 20 holes in each strip (see Fig.8). It is relatively straightforward to construct since all that is required to create the plug-in module is just ten wire links, twelve track-cuts, seven header/sockets, plus the piezo. We recommend following the usual sequence of construction:

- Cut required size stripboard
- Mark out the 12 track cuts
- Make the track cuts
- Insert the 10 wire links
- Insert the seven header pins/sockets
- Solder in piezo
- Mount the IPS screen, RTC module and IR receiver.

Along the way, carefully check each step. The only real point we need to emphasise is that the four connectors, J4, J5 (both 6-way), J6 (3-way), and J7 (2way) are all pin strips modified in the same manner as we did for the *DM*, and also for the *Electronic Dice* module. So, their pins are pushed to fully extend out of one side of the plastic housing, and the end result is inserted into the stripboard on the component side so that the pins extend downwards creating the plug-in ability (it may help to refer to Fig.9, where you can see J6 and J7 at the front of the board).

Running the test code for the MKC Clock

First, note that this month we are only going to load a program that will check the *IDM* has been assembled correctly. If all is well, it will show a simple clock display on the IPS screen. We are not going to go through the detail of the code until next month; so please don't worry if you see things in the program that you do not understand yet.

Now download the file **IDM_TestCode.txt** from the September page of the *PE* website and install it on your *MKC* (with the now familiar AUTOSAVE, Paste, and Ctrl-z sequence).

Before running the code, take a quick look at it in the EDITor. The first few lines should be familiar (apart from the BOX and TEXT commands). Note that main-program is just four lines long: a DO/LOOP that continually displays Time\$ and Date\$. There is also an infrared interrupt SUB that briefly activates the piezo sounder whenever an IR signal is received. The long list of what looks like random characters is actually the driver required to operate the IPS screen – put another way, it allows us to use MMBASICs graphical commands (such as BOX and TEXT) so that it correctly draws items on the IPS screen.

RUN the program and you will see the IPS screen show something similar to that shown in Fig.2 – however, the time and date will be incorrect. If you get an error message warning that the RTC is not responding, then check over the four connections to the RTC header (J2). With the *IDM* powered up, carefully remove the RTC module. The two outer pins should be at 3.3V (use a multimeter if you have access to one; otherwise, use a simple LED with a 470Ω series resistor and build a test probe – refer to Fig.7, *Part 2*). If this checks out then *power down* so that you can check continuity between J2 second and third pins to Micromite pins 18 and 17 respectively. An RTC error message will only be caused by an error on any these four connections.

Assuming you get no RTC error message, next press a button on an available remote control IR transmitter. Pressing any button should result in the piezo giving a brief 'beep'. If not, then first try another remote, then check the IR receiver is inserted correctly into J3 (the small rounded bump should be facing away from the RTC module – see Fig.9), and also

check the piezo connections. Ensure you get this working before moving on.

Now back to the IPS screen – if you don't see anything displayed then you will need to carefully check the eight connections between it and the Micromite. There is little guidance that can be provided here other than to say to check the track cuts and wire links are in the correct position, and the screen is inserted properly into J1.

By now, you should see a time and date (albeit incorrect) on the IPS screen. So the last thing we are going to do this month is to set the RTC with the correct time and date information. To do this, go to the command prompt (Ctrl-c) and use the command `RTC SETTIME year,month,day,hour,minute,second` to insert appropriate values. Note that this requires the hour parameter to be in 24-hour format. For example, to set the date/time for 16 August 2019, 10:54:30pm, use: `RTC SETTIME 2019,8,16,22,54,30`. When you press the enter key, and assuming you typed everything correctly, the date and time will be instantly loaded into the RTC with the parameter values you entered.

Now reset the MKC (press top-left button on DM) to synchronise the Micromite with the RTC time. The `OPTION AUTORUN ON` has been set in the code so it will automatically run on power-up. Confirm that you can indeed now see the correct date and time on the IPS screen. If it is incorrect, then simply press Ctrl-C and re-enter the correct parameters with `RTC SETTIME`.

The very last thing to demonstrate is a standalone setup. Remove power, unplug the IDM from the DM, and remove the DM from the MKC. Now plug the IDM directly into the MKC, and power it up. You should immediately see the IPS screen kick back into life. Congratulations, you have successfully assembled the *Mini MKC Clock* hardware. Leave it running for a few days and confirm there is minimal (if any) drift from the true time (use time from the internet or a mobile phone as a reference).

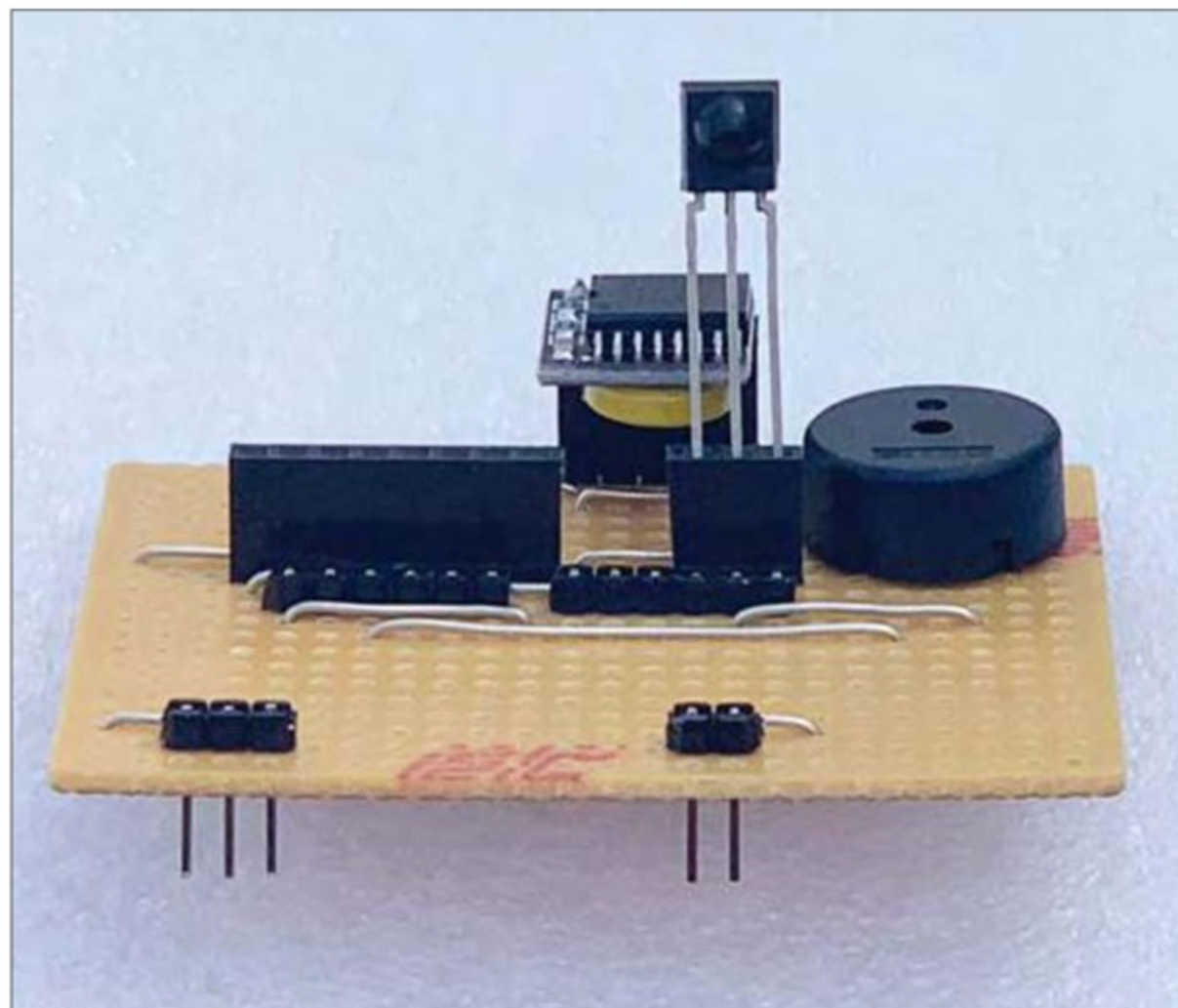


Fig.9. The assembled strip board for the IDM (the IPS screen not yet inserted).

Next month

Having assembled the IDM, next month we will begin to explore some of MM BASIC's graphical features; and also step through the code of the *Mini MKC Clock* program to understand how it works in its current form. Several new topics will be covered, including: RTC usage, `Date$` and `Time$`, how to use a special subroutine called `mm.startup`, and understanding what the Library is (and how it can be useful to 'hide away' our complex-looking screen driver code). Bringing all these elements together, we will end up adding several new features into the *Mini MKC Clock* program. Until next month, have fun!

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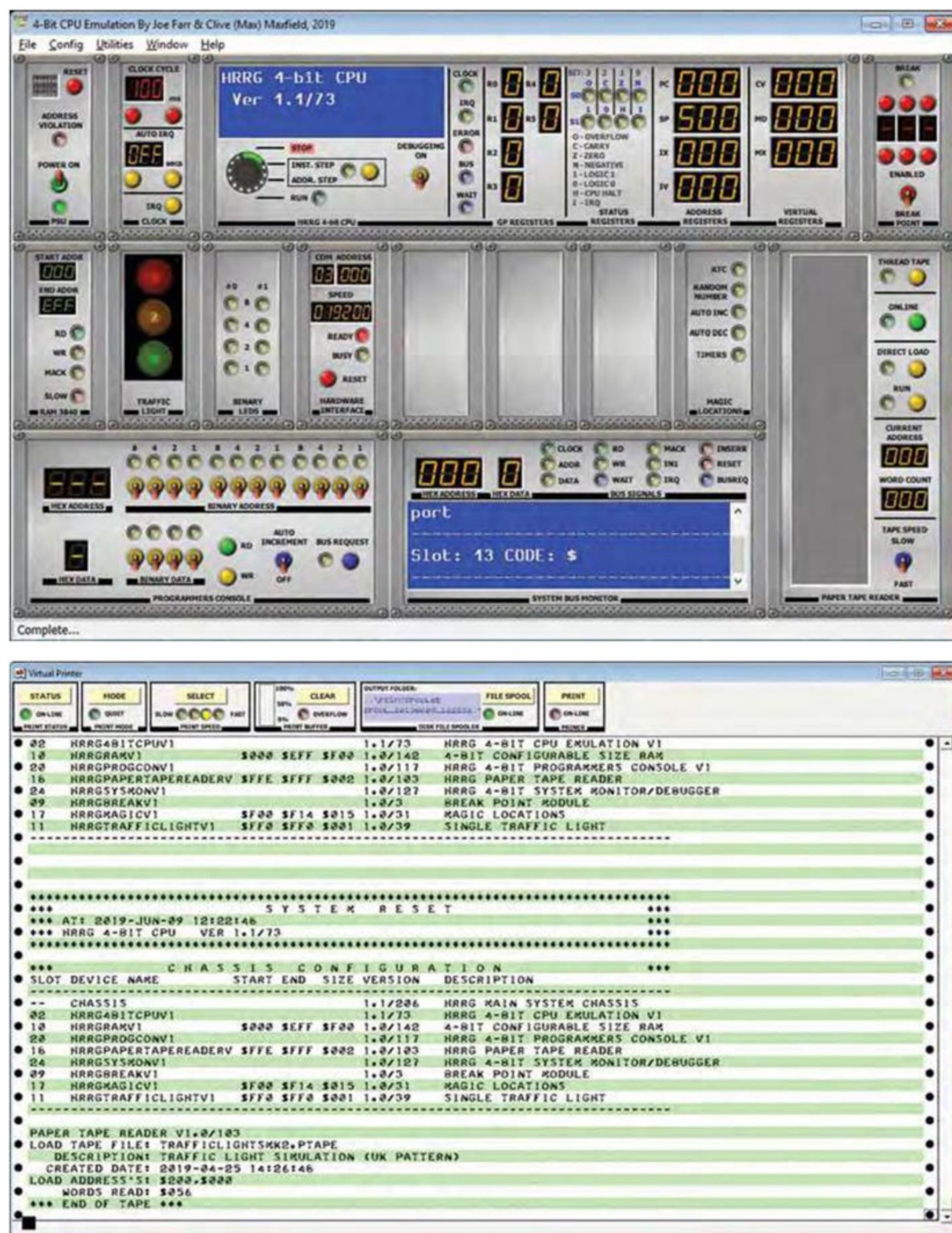
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By Max the Magnificent



Flipping and flopping – metastability



Virtual version of the 4-bit HRRG Computer.

If you recall, last month we discussed a project I'm working on called the 4-bit HRRG Computer – AKA, the Heath Robinson, Rube Goldberg Computer. This little gem of computational awesomeness will boast a wide variety of implementation technologies, from relays, vacuum tubes, transistors and jelly-bean ICs, to mechanical, magnetic, pneumatic, and fluidic logic... plus anything else I fancy. Intel can sleep easy (for now), a regular Pentium this is not.

My partner in Boolean crime is Joe Farr, who is initially creating a virtual version of the 4-bit HRRG Computer, while I focus on the 'real' (physical) side.

I started to explain that one challenge when building a computer from the ground up is that you have to face the problem of metastability, caused by reading asynchronous signals from the outside world. We took the simplest example – an asynchronous SR latch – and now it's time to move on to more substantial examples via the D-type flip-flop. (Incidentally, if

you missed last month's piece, but find this topic interesting, then I do recommend you read the August *Cool Beans* first – it will make the following much easier to understand.)

D-type flip-flop

A very common type of register is called a D-type flip-flop, where 'D' stands for data. Unlike the SR latch, which is *asynchronous*, the D-type flip-flop is a *synchronous* function that's controlled by a clock signal. The symbol, truth table, and example waveform for a positive-edge-triggered D-type flip-flop are shown in Fig.9.

From the truth table, we see that a positive, or rising edge (0-to-1 transition) on the CLK (clock) input will cause whatever 0 or 1 value is currently present on the D (data) input to be loaded into the register. This value will appear on the Q output after the register's propagation delay t_p . (These registers often have QB outputs, but we've omitted such an output in this case to keep things as simple as possible). A negative, or falling edge (1-to-0 transition) on the CLK signal will have no effect. Similarly, if the CLK is a steady 0 or 1, we don't care what's happening on the D signal, which we've indicated using 'X' characters, meaning 'don't care,' in the truth table.

By some strange quirk of fate, the heart of the D-type flip-flop is composed from two SR latches (or similar functions) accompanied by a few other primitive logic gates. We've already seen that SR latches can enter an unstable condition if we're not careful. The way the creators of the D-type flip-flop avoid this is to specify two parameters called 'setup' and 'hold'.

Basically, we are creating a 'window' surrounding the active edge of the clock. So long as the data signal has stopped changing before the start of the window (as specified by the setup time t_s), and so long as it remains steady until after the end of the window (as defined by the hold time t_h) then everything will be tickety-boo.

Consider the waveform diagram in Fig.9. When power is first applied to the system at time t_0 , the D-type flip-flop can randomly power up containing

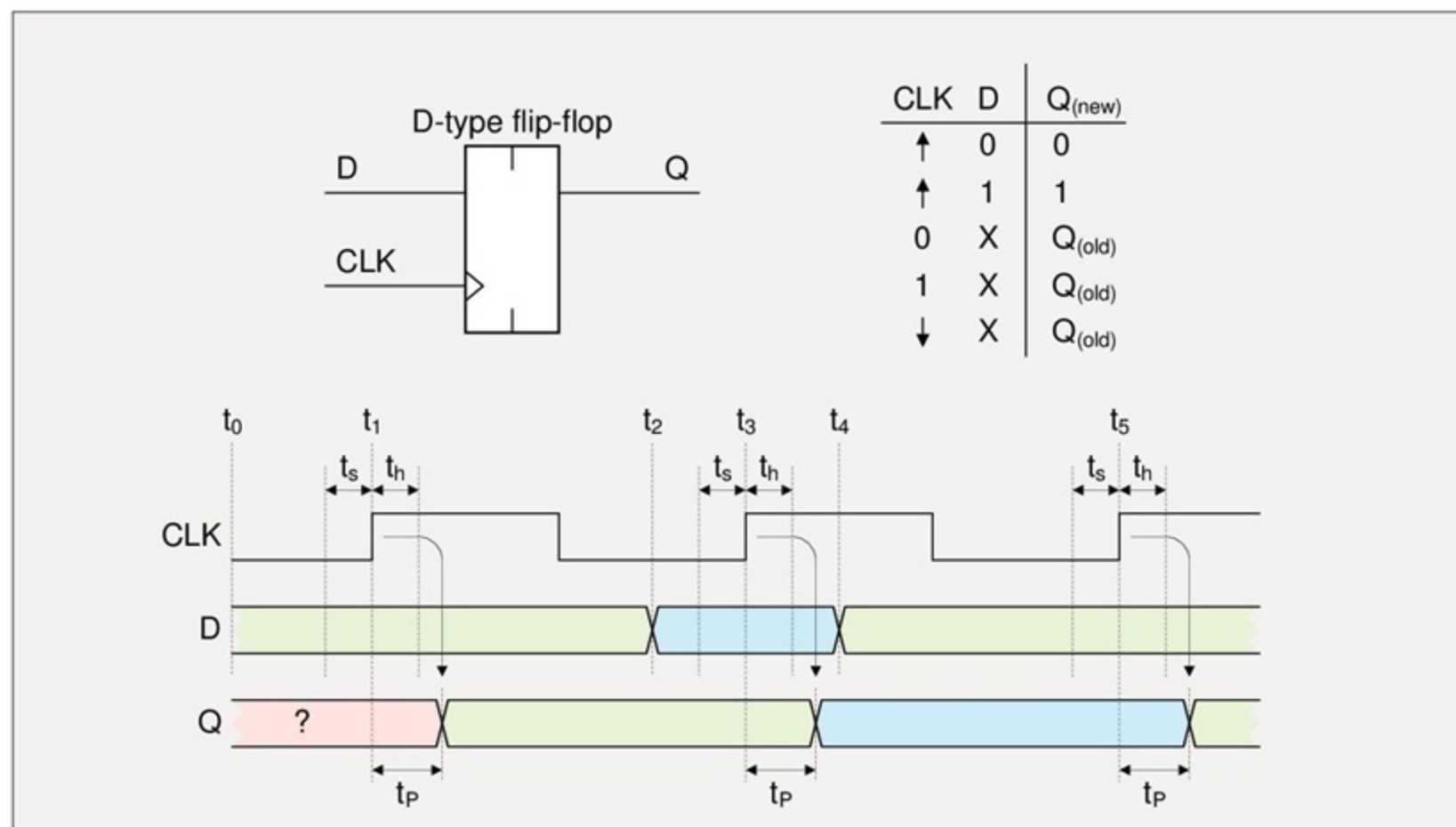


Fig.9. Symbol, truth table, and example waveform for D-type flip-flop.

a 0 or a 1; we've indicated this using the light pink color and the '?' character in the waveform. From the waveform diagram we see that the CLK signal starts at 0. Now, observe the waveform associated with the D signal. We've shown this as a light green 'box,' thereby indicating that the data can be a 0 or a 1; we don't care which, so long as it's a good steady signal.

The D signal is stable throughout the setup-hold window around the positive clock edge at time t_1 , so the value on D is loaded into the flip-flop, appearing on the Q output after the propagation delay t_p .

At time t_2 the value on D transitions from a 0 to a 1, or vice versa (we've indicated this new value in light blue). Since this occurs when the CLK is a steady 0, and since it occurs *before* the setup time associated with the clock edge at time t_3 , it has no effect on the contents of the flip-flop.

The D signal is stable throughout the setup-hold window around the positive clock edge at time t_3 , so the value on D is loaded into the flip-flop, appearing on the Q output after the propagation delay t_p .

At time t_4 the value on D transitions from a 1 to a 0, or vice versa (we have

indicated this new value in light green). Since this occurs when the CLK is a steady 1, and since it occurs *after* the hold time associated with the clock edge at time t_3 , it has no effect on the contents of the flip-flop.

Last but not least, the D signal is stable throughout the setup-hold window around the positive clock edge at time t_5 , so the value on D is loaded into the flip-flop, appearing on the Q output after the propagation delay t_p .

Monstrous metastability

Now let's consider what might happen if we happen to violate a setup or hold time, as illustrated in Fig.10. Things start off the same as in Fig.9. The problem occurs when the data transitions at time t_2 , thereby violating the setup time t_s associated with the rising edge on the clock at time t_3 . This may cause the register, and the Q output, to enter a metastable condition, the meaning of which we will discuss in a moment (alternatively, the register and its output could potentially start oscillating between 0 and 1). After a delay known as the 'recovery time', the register will randomly settle into a 0 or 1 value, but we don't know which one.

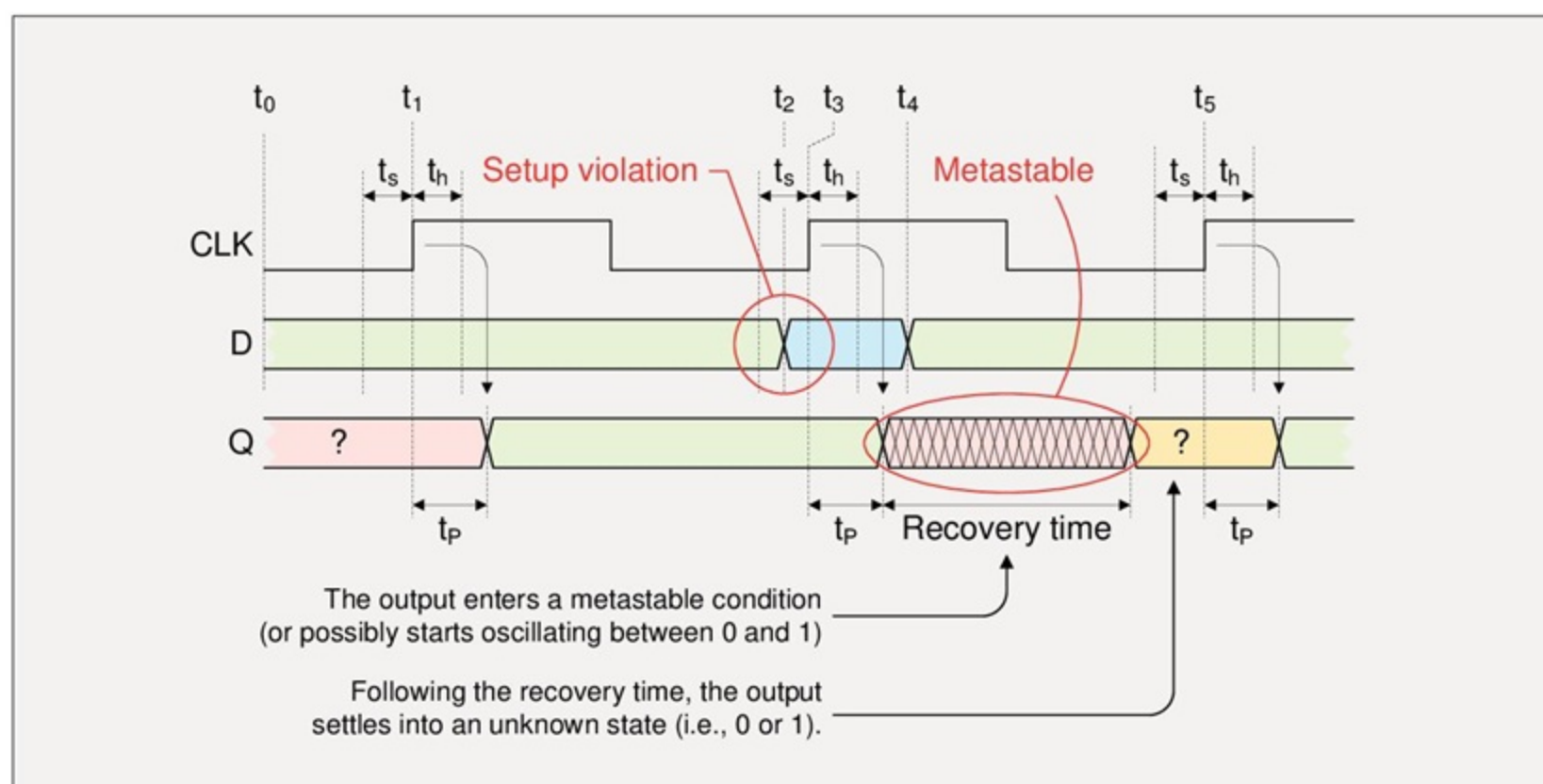


Fig.10. A setup violation on a D-type flip-flop.

It's only after the clock edge at time t_5 that a known good value is once again loaded into our flip-flop.

So, what do we mean by 'metastable condition'? Well, one way to think about this is illustrated in Fig.11. Suppose we have two guys called 'Zero' and 'One' kicking a football back and forth over a grassy knoll. First, Zero kicks the ball to One (a), then One kicks the ball back to Zero (b).

The problem arises if someone doesn't kick the ball hard enough, such that it ends up perched on top of the knoll. We can think of this as a system being in an unstable equilibrium, in which it will remain until a gust of wind or vibrations from a passing truck cause it to roll one way or the other.

Something similar may happen inside our D-type flip-flop when we violate a setup or hold time. In this case, one or more of the flip-flop's internal signals may end up at some intermediate voltage – our metastable state – where they will remain for some period of time (not to exceed the recovery time) before settling into good 0 or 1 values.

Mastering Metastability

Now, you may be saying to yourself, 'This is very interesting (or not, as the case might be), but I never do anything that might cause metastability, so what has it got to do with me?' The thing is, since you regularly interact with microcontrollers (MCUs) in such things as home appliances, automobiles, and smart devices, you are quite possibly the instigator of numerous metastable events each and every day. The reason you remain blissfully unaware of this fact is that the designers of the MCUs have taken steps to protect you from yourself.

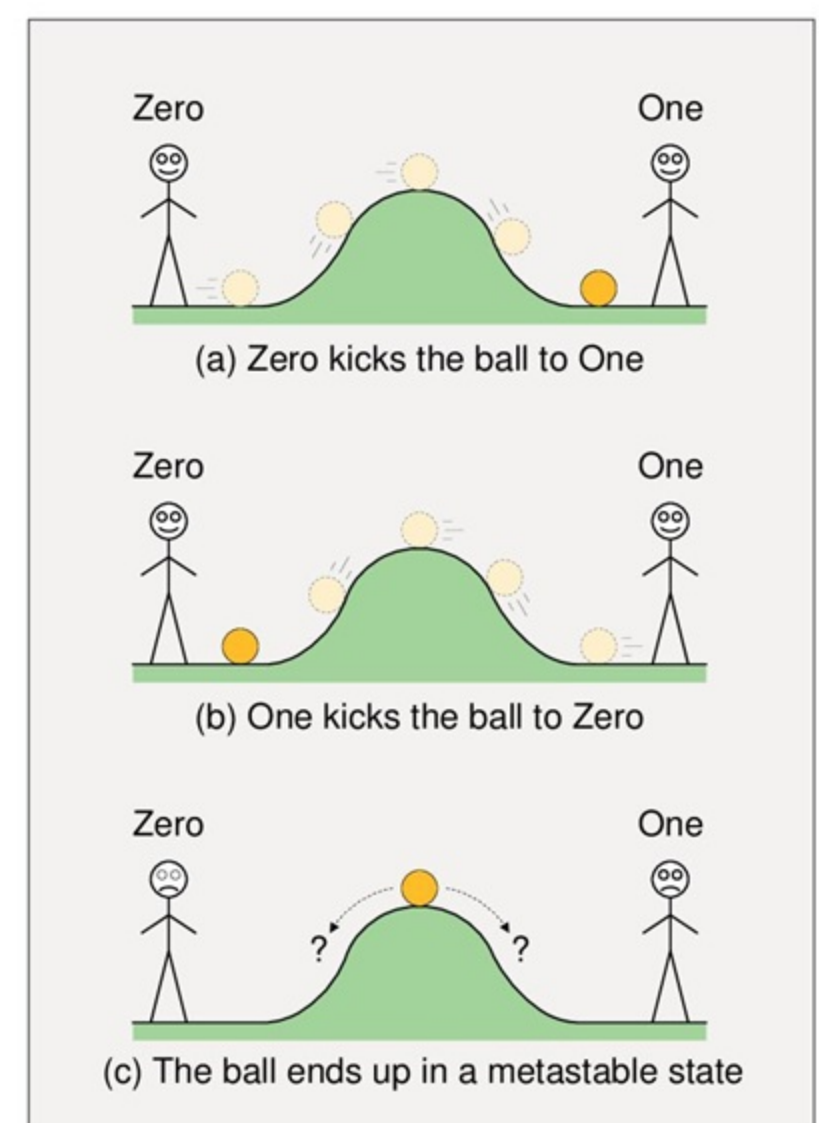


Fig.11. Visualisation of metastability.

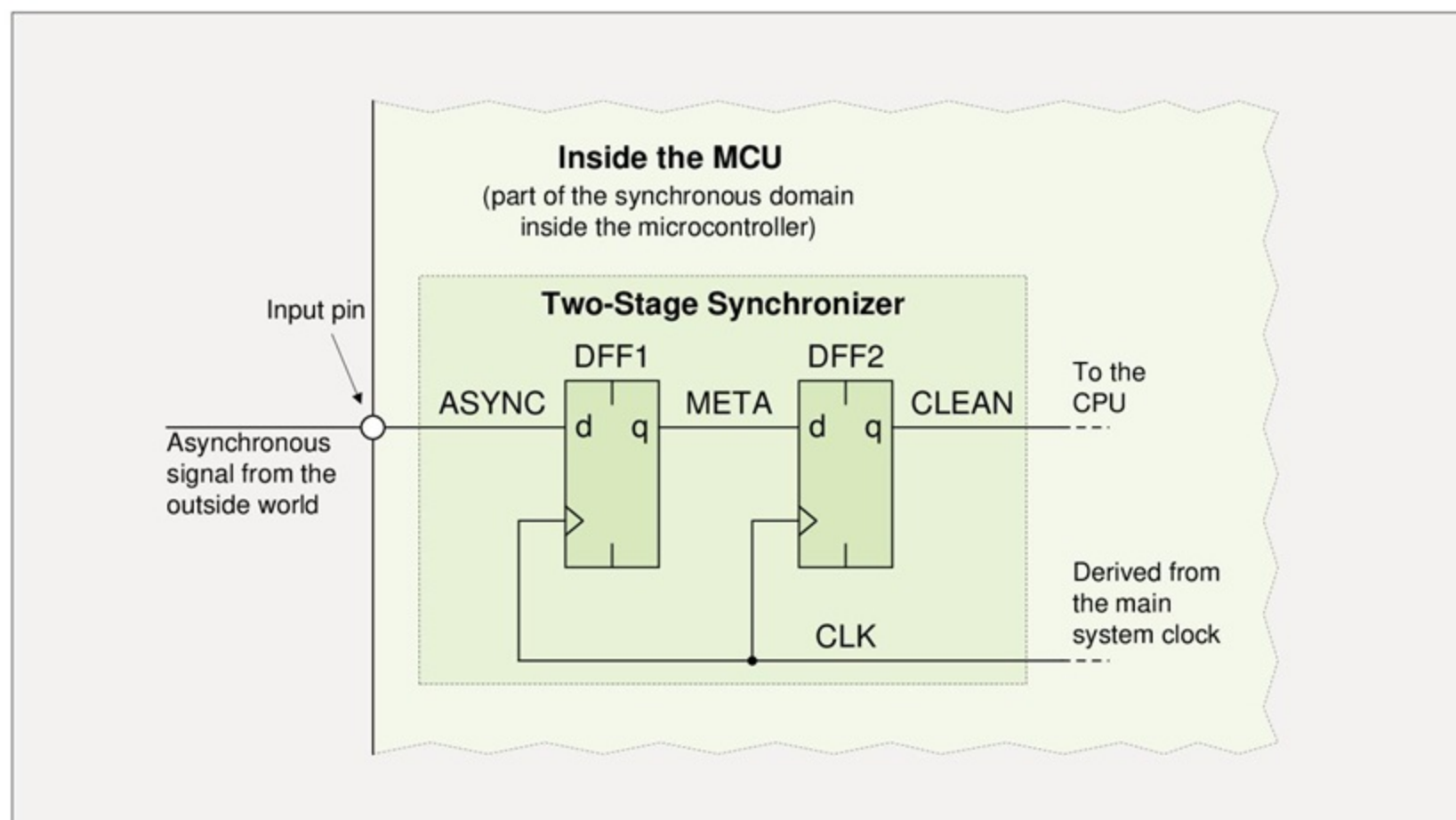


Fig.12. A two-stage synchroniser

The realm inside a microcontroller is regular and structured, with every action being synchronised to the system clock. But what about the real world outside the MCU? Here, actions can take place willy-nilly whenever they please, which means they are asynchronous (not synchronised) with respect to the MCU's clock.

As an example, suppose you are creating a hobby project using an Arduino. Let's say you connect a toggle switch to one of the Arduino's digital input pins that you've decided to call `myInputPin` in your code, and you also declare a variable called `mySwitchValue`. At some stage in your program, you're going to have a statement that says something like:

```
mySwitchValue =
digitalRead(myInputPin);
```

Did you ever pause to ponder what actually happens when such a statement is executed? Well, there are several steps, the first of which is to access the value on the pin and store it in a register. If it happens that this statement is executed at the same time as you are toggling your switch, you could violate the register's setup or hold time, thereby triggering a metastable condition, which could really

mess things up inside the MCU and give you a 'bad hair' day – even if you have as little hair as the editor and me.

Two-stage synchroniser

One solution is to attach what's called a two-stage synchroniser to the input pin inside the MCU (Fig.12). As we see, in addition to our CLK (clock) signal, we have three data signals: ASYNC (the asynchronous input from the outside world), META (the output from the first D-type flip-flop that may enter a metastable state), and CLEAN (the output from the second flip-flop that has been scrubbed clean of any metastability).

Let's start by considering the case where the transition on the asynchronous input doesn't cause any problems by triggering any violations (Fig.13). We start with the asynchronous signal (ASYNC) coming from our toggle switch and the outputs from the two registers (META and CLEAN) all containing the same 0 or 1 value (we don't care which), which we've indicated in light green.

Eventually, we activate our toggle switch, thereby causing the ASYNC signal to change to a new 0 or 1 value, which we've indicated in light blue. The rising edge on the CLK signal at time t_1

causes the new value on ASYNC to be loaded into the first flip-flop, appearing on its META output after the register's propagation delay t_p . At the same time, the original value on META is loaded into the second flip-flop, appearing on its CLEAN output after that register's propagation delay t_p .

Now consider the rising edge on the CLK signal at time t_2 . This reloads the new value on ASYNC into the first flip-flop. At the same time, the new value on the META signal is loaded into the second flip-flop. Thus, not surprisingly, it now takes two clock cycles for the new value on the ASYNC signal to wend its way through the two registers to become available to the MCU.

Next, let's consider what might happen if the transition on the ASYNC signal were to trigger a setup or hold violation on the first flip-flop. Let's assume a setup violation, as illustrated in Fig.14.

In this case, the rising edge on CLK at time t_1 causes the first flip-flop to enter a metastable condition, which appears on its META output after the register's propagation delay t_p . At the same time, the original value on META is loaded into the second flip-flop, appearing on its CLEAN output after that register's propagation delay t_p .

Following its recovery time, the first flip-flop will settle in a random 0 or 1 state. Suppose it were to end up with the value we were actually hoping for. In this case, following the rising edge on CLK at time t_2 , the two flip-flops and the ASYNC, META, and CLEAN signals end up just the same as if there had been no violation.

Of course, there's always the possibility that, following the recovery time, the first flip-flop ends up containing the wrong 0 or 1 value (the one we weren't hoping for) as depicted in Fig.15.

In this case, the rising edge on CLK at time t_2 finally loads the good value on ASYNC into the first flip-flop, but – at the same time – it loads the bad value into the second flip-flop, and this unwanted value appears on the CLEAN output after

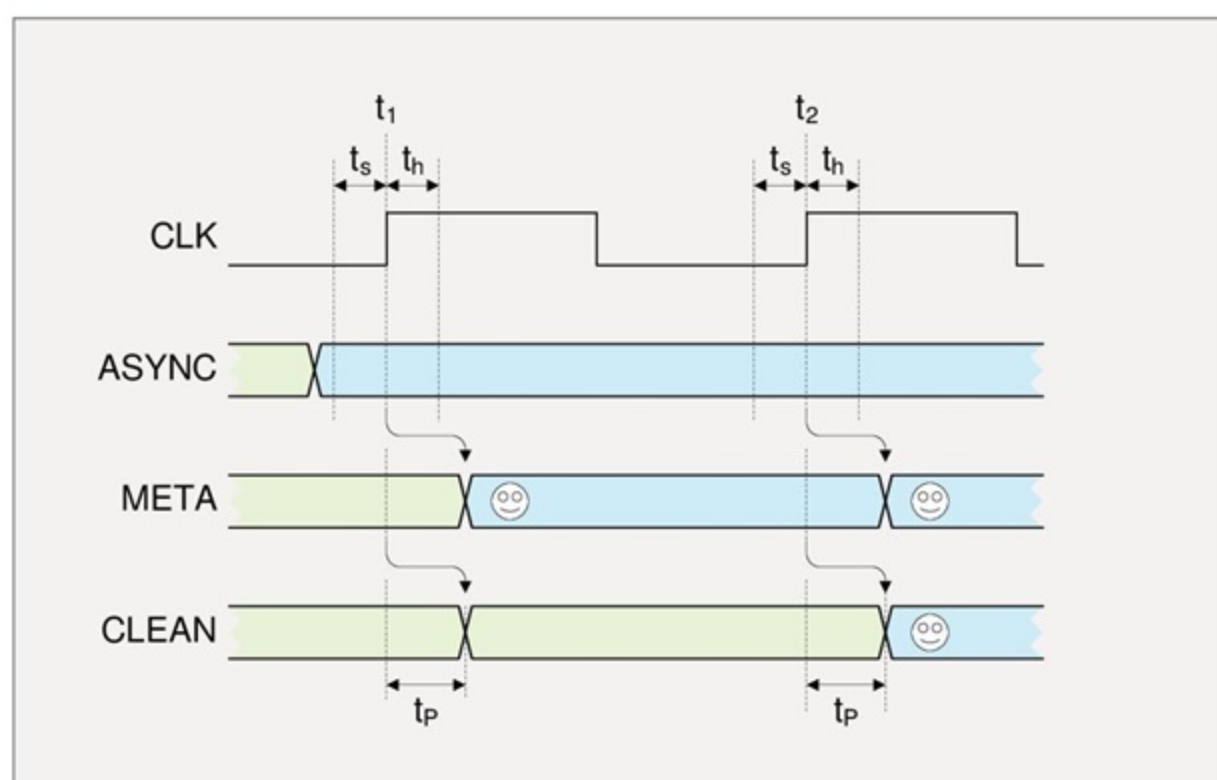


Fig.13. No problems (hurray!)

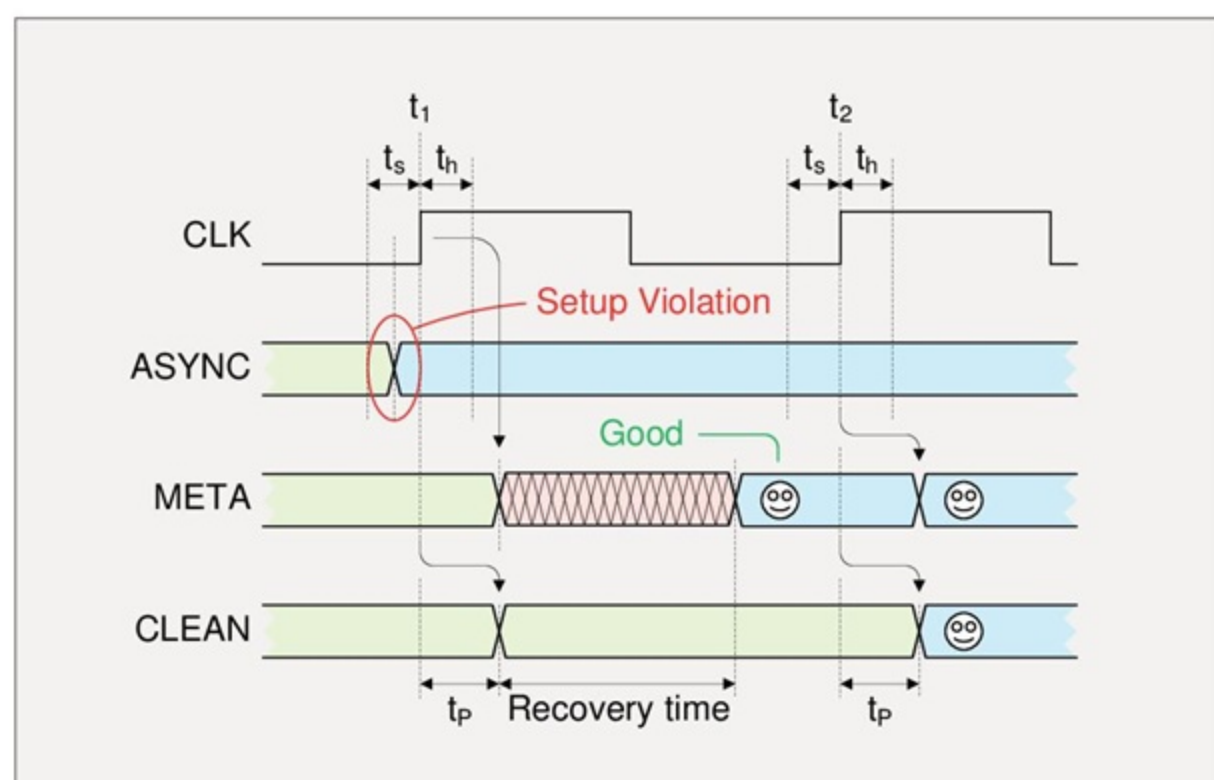


Fig.14. A setup violation that ends up the way we want.

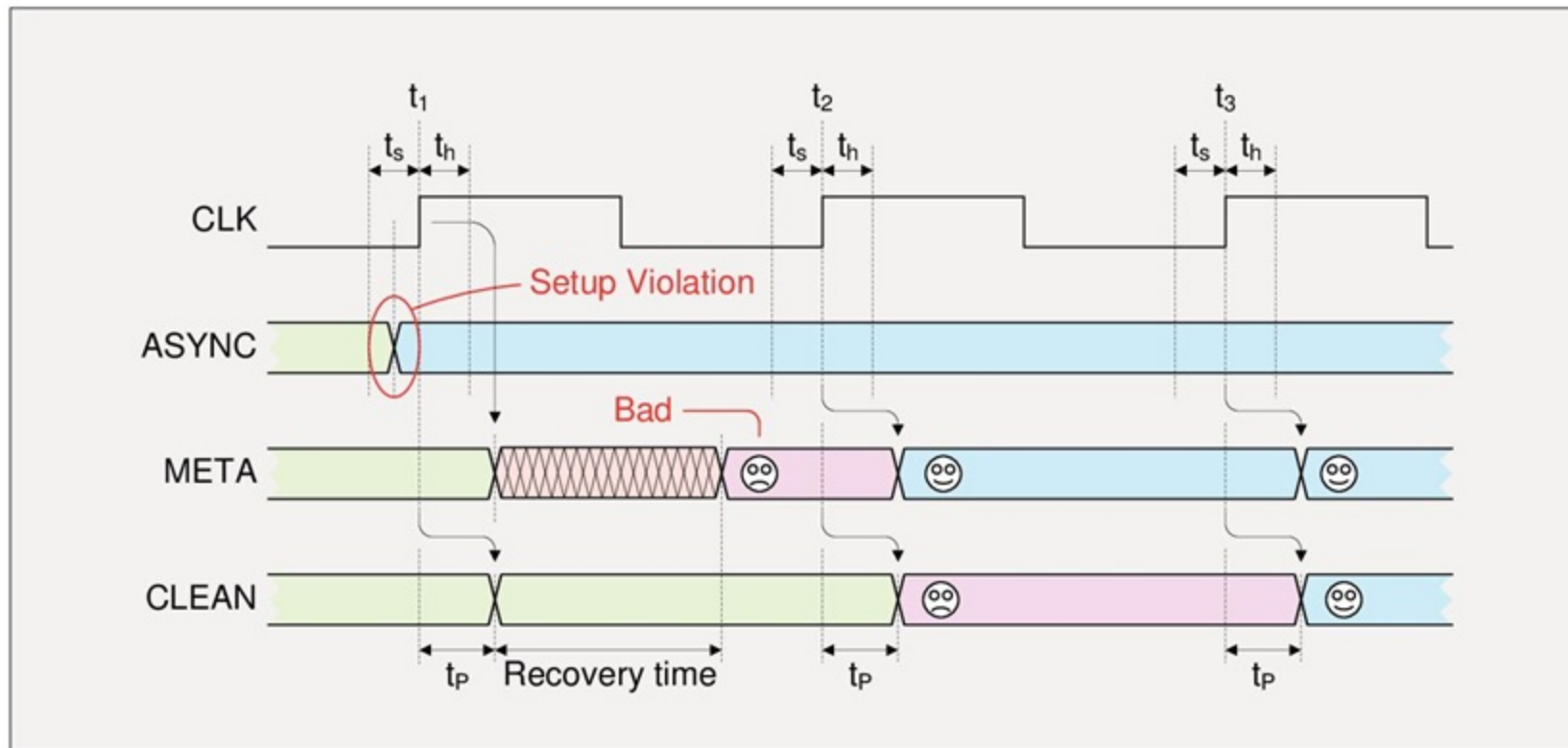


Fig.15. A setup violation that ends up the way we don't want.

the second register's propagation delay. Thus, it's not until the rising edge on the CLK at time t_3 that the second flip-flop and the CLEAN signal end up with the value we were looking for.

Three steps to (stability) heaven

What does all this really mean? Well, in a nutshell, our two-step synchroniser requires three active clock edges to perform its magic. It's only after the third clock that we can guarantee our CLEAN signal contains the value we want.

Although using three clock cycles may seem like a wasteful extravagance,

it's important to realise that events in the real world take place at a vastly different time scale than do the operations inside the MCU. In the case of our hand-activated toggle switch, for example, the fastest most people could flick this back and forth would be about five times a second (and that would be really pushing things). So, even under worse-case



Cool bean Max Maxfield (Hawaiian shirt, on the right) is editor-in-chief at **EEWeb.com** – the go-to site for users of electronic design tools and askers of electronic questions.

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conditions, the switch could be activated and deactivated once every 200ms, which equates to 3,200,000 clock cycles on a 16MHz Arduino. This means that it really doesn't impact the speed of our program if the MCU devotes three of these clock cycles to driving our two-stage synchroniser.

Happy HRRGs

As we previously noted, most end users don't even think about the problems associated with metastability because the folks who design microcontrollers mitigate against these effects for us. However, when one is building an electronic system from the ground up – like our *4-Bit HRRG Computer*, for example – then we have to cover all of the bases. For example, we have to make decisions about things like the CPU's internal registers and its instruction set (the instructions it will support and how they will behave). By some strange quirk of fate, these topics will be the focus of a future *Cool Beans* column. Until then, have a good one!



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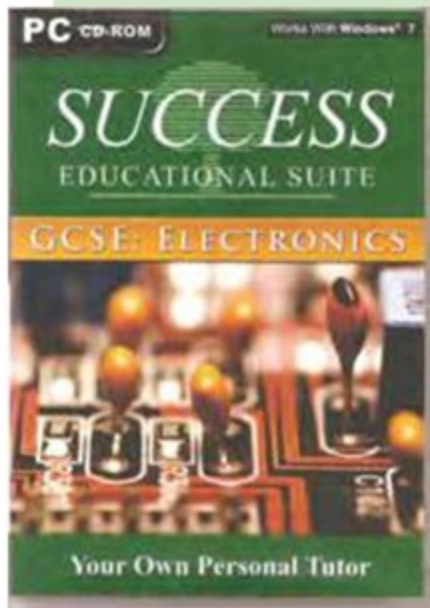




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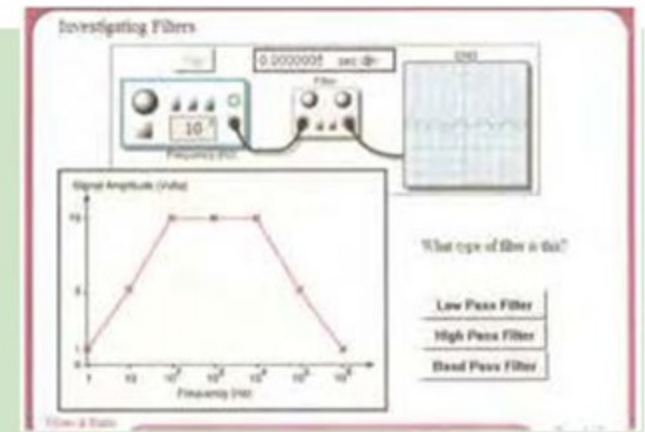
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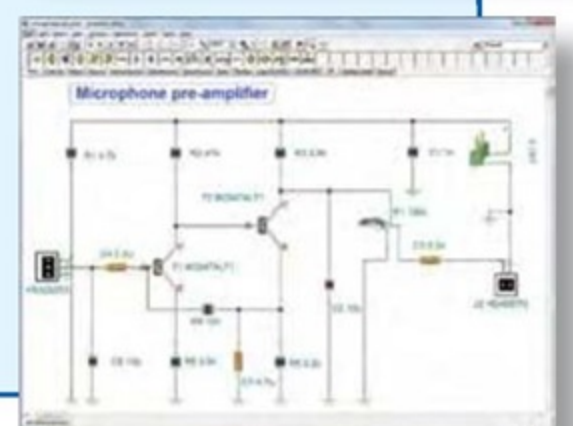
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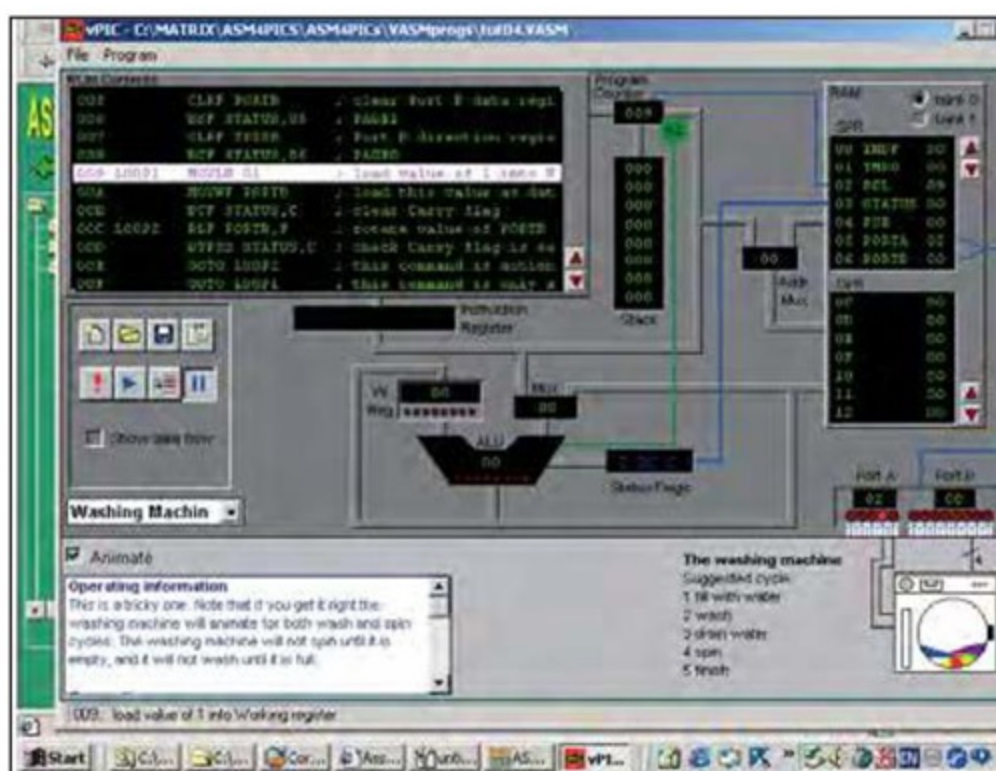
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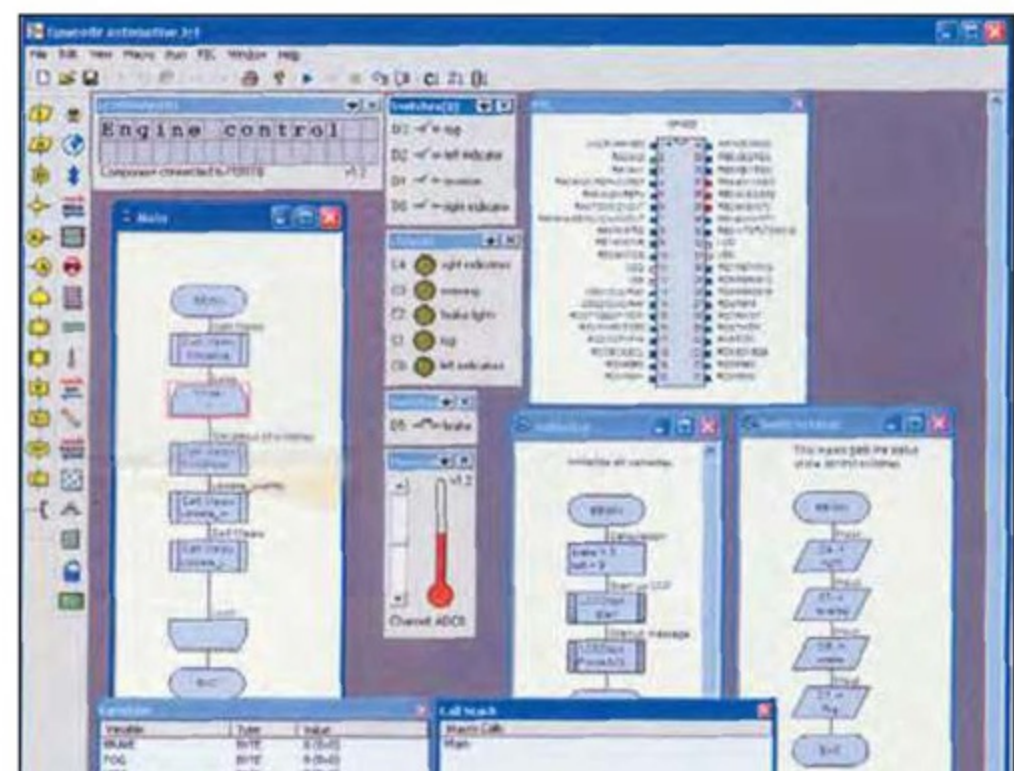


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Teach-In 2017

Introducing the BBC micro:bit



PYTHON CODING ON THE BBC MICRO:BIT

Jim Gatenby

Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

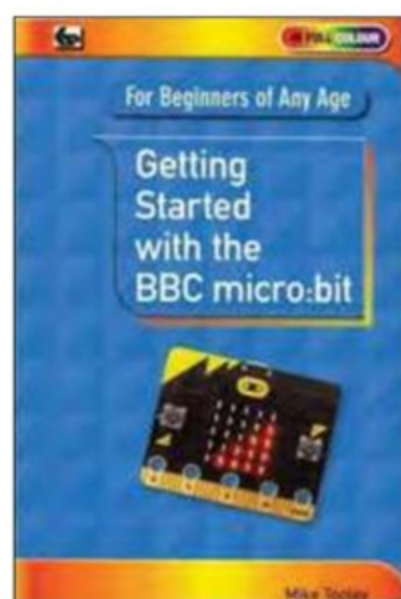
Among the many topics covered are: main features of the BBC micro:bit including a simulation in a web browser screen; various levels of programming languages; Mu Editor for writing, saving and retrieving programs, with sample programs and practice exercises; REPL, an interactive program for quickly testing lines of code; scrolling messages, creating and animating images on the micro:bit's LEDs; playing and creating music, sounds and synthesized speech; using the on-board accelerometer to detect movement of the micro:bit on three axes; glossary of computing terms.

This book is written using plain English, avoids technical jargon wherever possible and covers many of the coding instructions and methods which are common to most programming languages. It should be helpful to beginners of any age, whether planning a career in computing or writing code as an enjoyable hobby.

118 Pages

Order code PYTH MBIT

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GETTING STARTED WITH THE BBC MICRO:BIT

Mike Tooley

Not just an educational resource for teaching youngsters coding, the BBC micro:bit is a tiny low cost, low-profile ARM-based single-board computer. The board measures 43mm x 52mm but despite its diminutive footprint it has all the features of a fully fledged microcontroller together with a simple LED matrix display, two buttons, an accelerometer and a magnetometer.

Mike Tooley's book will show you how the micro:bit can be used in a wide range of applications from simple domestic gadgets to more complex control systems such as those used for lighting, central heating and security applications. Using Microsoft Code Blocks, the book provides a progressive introduction to coding as well as interfacing with sensors and transducers.

Each chapter concludes with a simple practical project that puts into practice what the reader has learned. The featured projects include an electronic direction finder, frost alarm, reaction tester, battery checker, thermostatic controller and a passive infrared (PIR) security alarm.

No previous coding experience is assumed, making this book ideal for complete beginners as well as those with some previous knowledge. Self-test questions are provided at the end of each chapter, together with answers at the end of the book. So whatever your starting point, this book will take you further along the road to developing and coding your own real-world applications.

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ARDUINO

Teach-In 2016

See opposite for our popular introduction to the Arduino



ARDUINO FOR DUMMIES

John Nussey

Arduino is no ordinary circuit board. Whether you're an artist, a designer, a programmer, or a hobbyist, Arduino lets you learn about and play with electronics. You'll discover how to build a variety of circuits that can sense or control real-world objects, prototype your own product, and even create interactive artwork. This handy guide is exactly what you need to build your own Arduino project – what you make is up to you!

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Jeremy Blum

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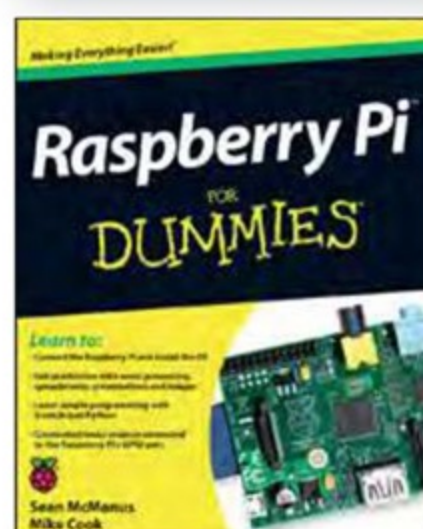
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RASPBERRY PI FOR DUMMIES

Sean McManus and Mike Cook

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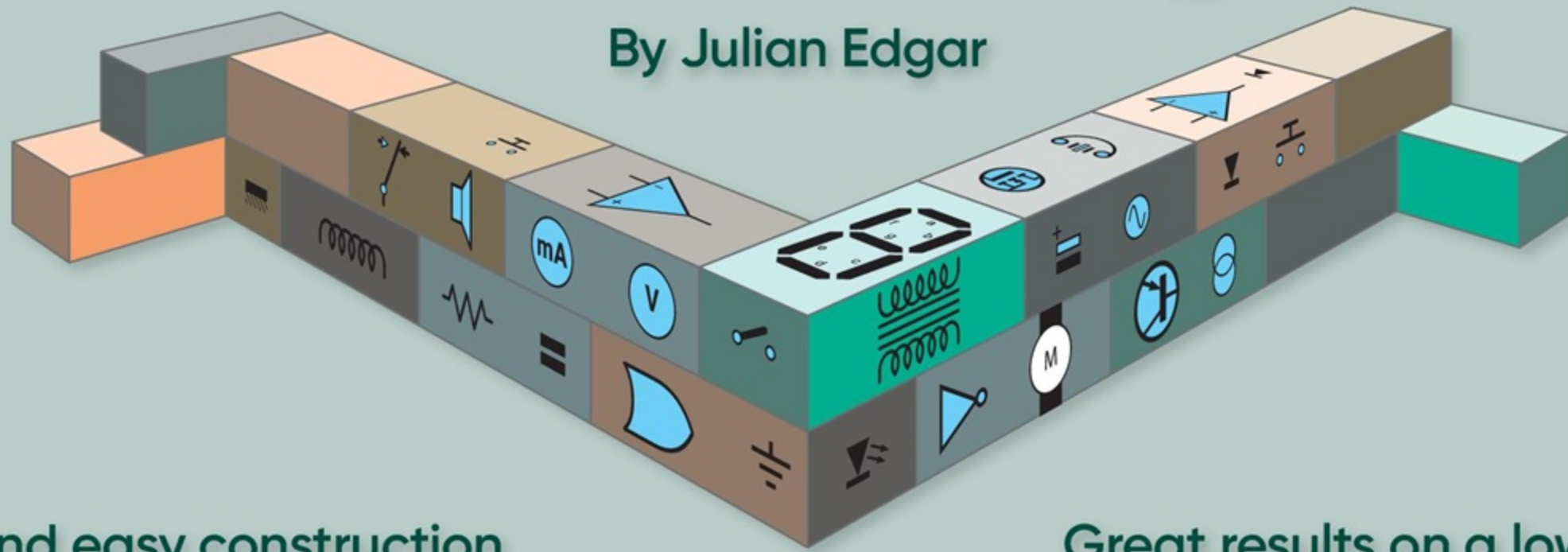
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By Julian Edgar



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Three clocks

Throughout the ages, people have always had a fascination with time – and mechanisms that display it. This month, let's take a look at three different clocks.

Rotating LED Clock

This clock module is available prebuilt or in kit form and costs about £5 (and up), delivered. To find it, search on eBay under 'Rotating DIY DS1302 LED Electronic Digital Clock Kit 51 SCM Learning Board 5V'. Note that there seem to be two varieties – one with surface-mount LEDs (Fig.1) and another with through-hole LEDs. Which you choose is up to you, but the SMD version is generally pricier.

The clock comprises a PCB that's 81mm square. Around the outside are located 60 LEDs, indicating seconds. Every fifth increment is red; the other LEDs are green. Also sited on the front face is a 4-digit, red LED display that's 14mm high, plus assorted surface-mount components.



Fig.1. The rotating LED clock in its night glory. The 60 LEDs around the periphery can be programmed with different functions. Here, a red LED is showing every 5-second increment, and a green LED moves around like a second hand.

On the back is a large Atmel micro-controller, a piezo buzzer, a crystal and three buttons. A holder is also provided for the CR2032 battery (not supplied) that's required to maintain the time if power is lost. A USB power supply cable is provided – ie, the clock requires a 5V supply.

To put it mildly, the provided instructions are terrible. However, if you play around long enough with the buttons, you'll find you can set the year, month and day (US style – with month first then day), hours and minutes. You can apparently also set an alarm, but I never figured out how to do that.

The real fun with the clock is that you can make the outer ring of LEDs work in all sorts of ways. By pressing the 'plus' key (not the 'mode' key as you might assume) you can have anything from 'mild' (seconds counted by a green LED that moves around the circle) to 'wild' (all the LEDs pulsing at high frequency). I went for the LED mode that's closest to a second hand moving around the display.

The main LED numerical display shows hours and minutes (hours in 24-hour time), and then periodically shows year, day of the month and month. Room temperature is then shown, before the display reverts back to time.

On the hour, the buzzer sounds (quietly, if you leave the protective sticker on) and the outside LEDs do a fancy dance.

You could mount the PCB in a box with a translucent front panel, but I think the style and approach of the module best lends itself to a desk or workshop clock for a tech person (ie, you!), where all the electronics are left on display. The PCB is provided with long spacers and the clock module



Fig.2. The Rotating Clock LEDs are bright and easily read from a distance. The module comes as a kit or prebuilt and costs from £5, delivered.

sits upright on these spacers, making it easy to place on a flat surface. The LEDs are bright and can be easily read from across a room.

As I say, playing longer with the controls may yield further functions that I



Fig.3. The rear of the Rotating LED Clock shows the optional CR2032 battery back-up. The clock is normally powered via a 5V USB supply.

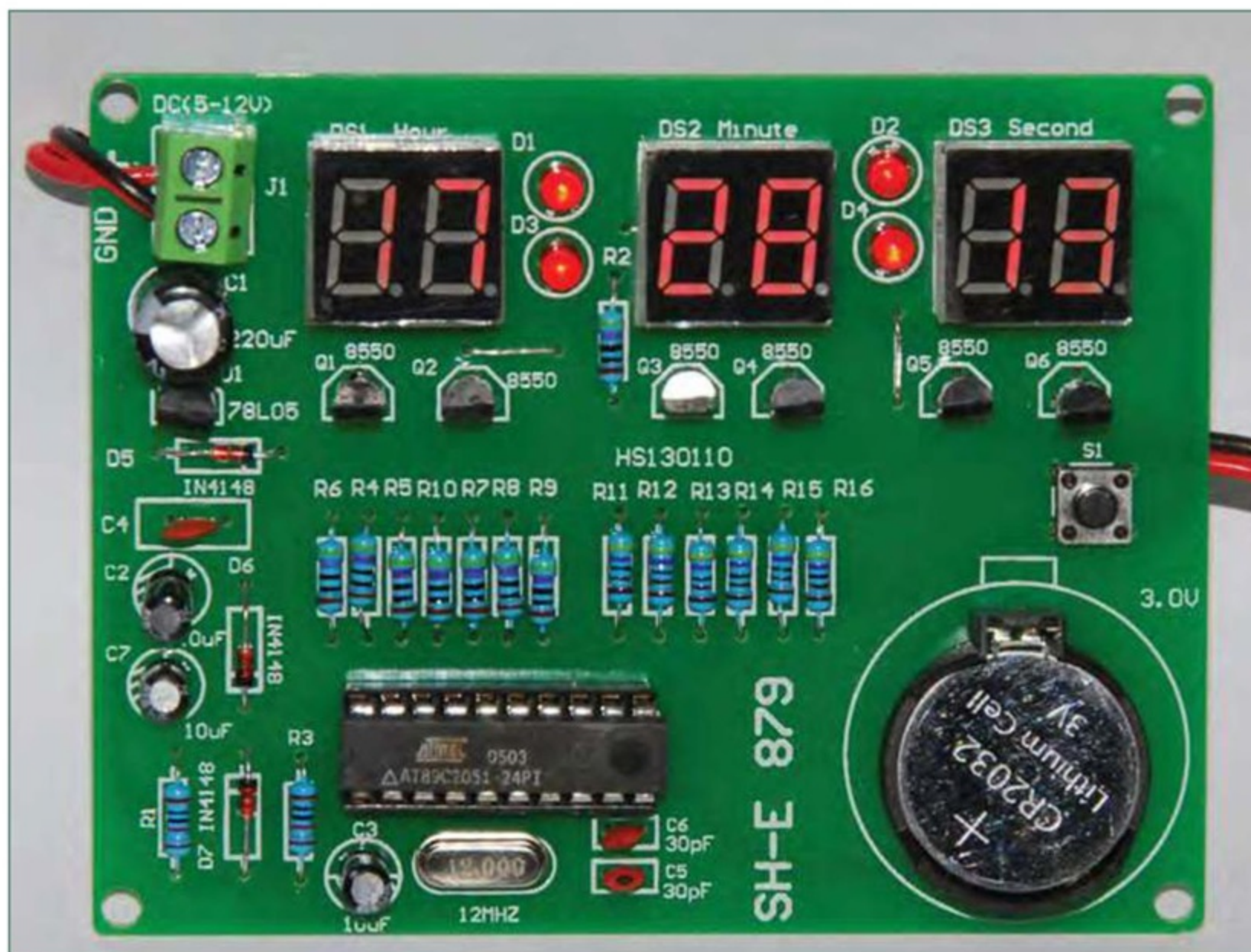


Fig.4. This clock comes as a kit. It has only one function – showing the time – but the kit is easily constructed and uses battery back-up. It's a great choice for a beginner.

didn't find, but just limiting it to those that I did find, I thought it a fun bit of gear. Perched on my desk, it attracted a lot of comment!

LED Kit Clock

The next clock module is sold as a kit – and a very cheap one too (see Fig.4). It will cost you under £3, delivered. To find it, search eBay under 'DIY Kit Module 9V-12V AT89C2051 6 Digital LED Electronic Clock Parts 9UK' (eg, eBay item 141971072785, £2.41 delivered at the time of writing). Compared with the previous clock, it's a bit 'plain Jane', but it's also a quite straightforward kit to construct, and that makes it potentially a good fit for beginners or schools.

The PCB is 90 × 70mm and uses three two-digit LED displays, each 10mm high. Between the numerical displays, non-flashing colons are formed by individual LEDs. (All LEDs are red.) The supply voltage is 6V to 12V; and, as with the previous module, back-up of the user-programmed time is via a CR2032 battery (not supplied).

The time display is in 24-hour time, but no other functions (eg, date, year, temperature, alarm) are provided.

The board overlay is clear and the solder pads of a decent size, and not placed too close together. When assembling the kit, do note these points:

- Install the three wire links first, as one is placed under one of the two-digit displays

- One of the individual LEDs is reversed in polarity over its three brothers. The PCB overlay is correct, but it initially looks odd
- The 7805 regulator looks just the same at a glance as the six 8550 transistors, so don't get them mixed up
- The battery holder mounts so its lug is placed closest to the LED displays.

After the clock has been constructed and powered-up, pressing the single button for a long period puts the clock into 'setting' mode, and then it's straightforward to set the hours and minutes. The seconds doesn't appear to be able to be set, so if you want this accurate, power up the clock just as the minute ticks over (it starts counting from zero).

I wouldn't give this kit to someone who has never built one before, but as a second or third kit, it would be ideal.

Universal Timer Module

To round off this month, Fig.5 shows an interesting universal timer module – but why is it in a column about clocks? Well, the LED display can be set to show real time, and this is maintained via battery back-up even when power is lost. Therefore, rather than just being a timer module, it's a 'real-time' timer.

The module works off any supply voltage from 5-60V and has a relay output. You will need to provide the CR1220 battery for time back-up.

Space doesn't allow a full description of all the functions, but the module can operate the relay for a defined period daily, on a specific day of the week, or on a specific day of the month.

The time can be continuously displayed or can be switched off in a battery-saving mode, and the on-board buzzer can sound when the relay operates, or it can be deactivated.

Find the module on Banggood (ID: 1314176) for just under £5, delivered.

Next month

In the October issue, I'll look at a variety of items that are suitable for use with your car. However, even if you're not interested in automotive electronics, all the products also have non-automotive uses.

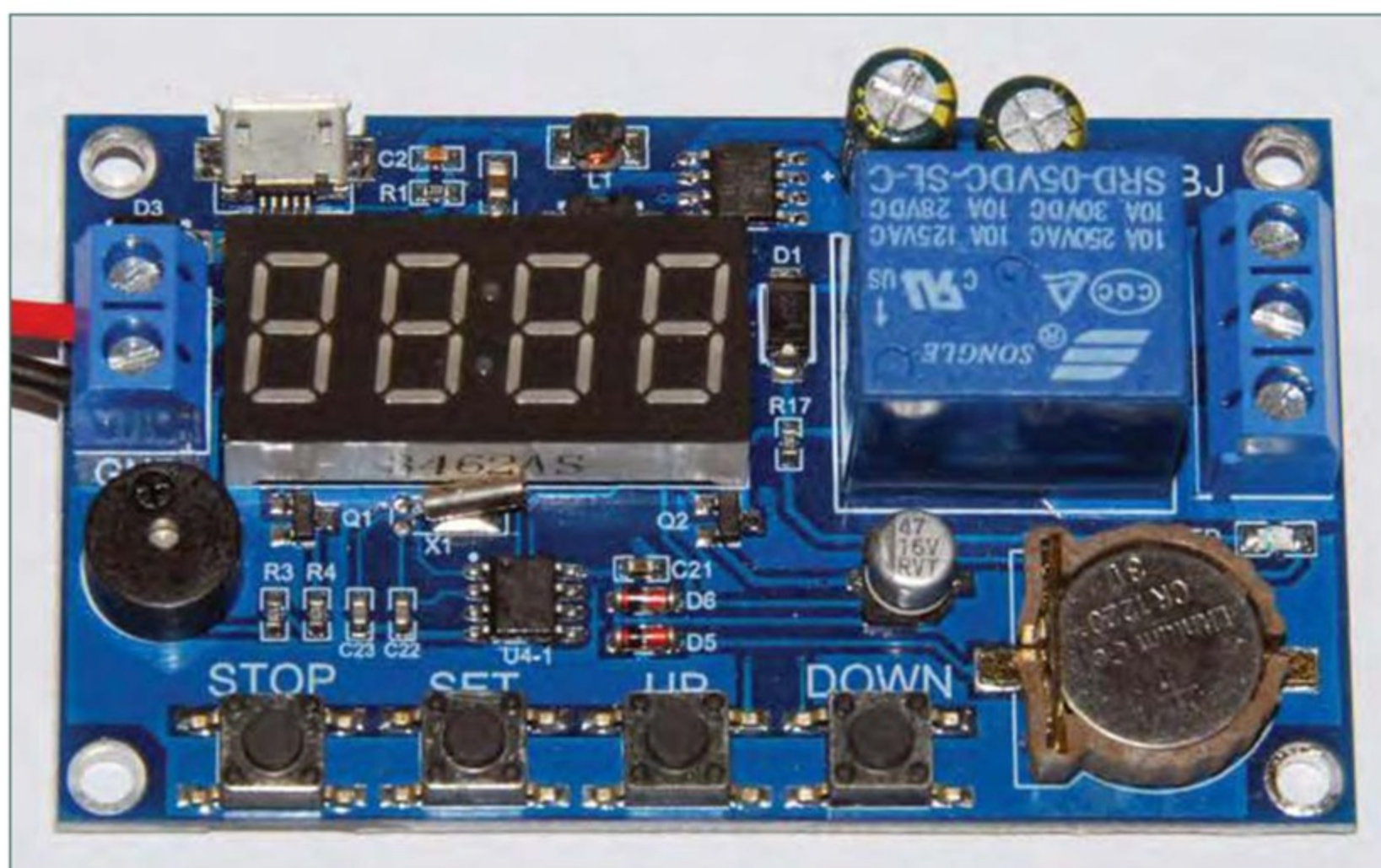


Fig.5. This module integrates a real-time clock with a programmable relay output. Timed periods can be set for activation on a daily, weekly or monthly basis.



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Always check price and availability in the latest issue or online. A large number of older boards are listed for ordering on our website.

We do not supply kits or components for our projects. For older projects it is important to check the availability of all components before purchasing PCBs.

Back issues of articles are available – see Back Issues page for details.

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Tel 01202 880299 Email: stewart.kearn@wimborne.co.uk

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Practical Electronics reaches more UK readers than any other UK monthly hobby electronics magazine. Our sales figures prove it.

We have been the leading monthly magazine in this market for the last twenty-seven years.

BOWOOD ELECTRONICS LTD

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www.bowood-electronics.co.uk

Unit 10, Boythorpe Business Park, Dock Walk, Chesterfield, Derbyshire S40 2QR. Sales: 01246 200 222

Send large letter stamp for Catalogue

The British Amateur Electronic Club at:

baec.tripod.com

Has many interesting articles on computers; digital electronics and analogue electronics.



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For editorial contact details see page 7.

Next Month – in the October issue

Opto-Isolated Mains Relay

Keep the bitey bits out of harm's way! If you need to switch mains voltages, say from a micro's output or any other low-voltage source, you need to isolate them, which is precisely what this project does.

GPS-synced Frequency Reference

This lab-quality programmable design is perfect for critical tasks when a really accurate and stable frequency reference is needed. Chances are, whatever frequency you require, this Micromite-BackPack-based project can provide it. Exactly!

Digital Command Control Programmer for Decoders

DCC – Digital Command Control – is a widely used method for controlling model railways, especially when running multiple locos/trains on the same track(s). This USB DCC programmer is simple, cheap and easy to build.

Audio Out

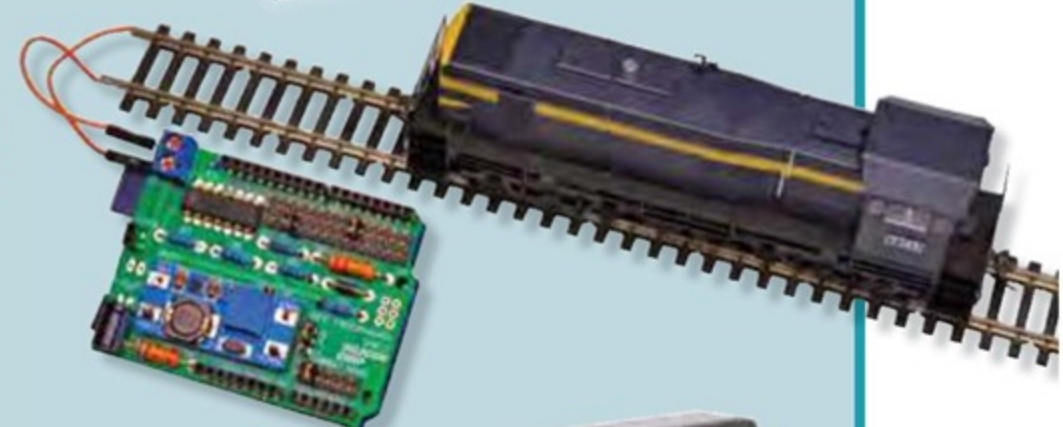
Next month, more essential loudspeaker groundwork, with a focus on crossover options for our superb LS3/5A mini-monitor project.

Make it with Micromite

Explore some of MMBASIC's graphical features, and step through the code of the Mini MKC Clock program to understand exactly how it works.

PLUS!

All your favourite regular columns from *Cool Beans*, *Circuit Surgery* and *Electronic Building Blocks* to *Techno Talk* and *Net Work*.



On sale 5 September 2019

Content may be subject to change

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Development Tool of the Month!

MPLAB® ICD 4 In-circuit Debugger



Part Number
DV164045

Overview:

The new MPLAB® ICD 4 introduces a faster processor and increased RAM to deliver up to twice the speed of ICD 3 for the in-circuit debugging of PIC® MCUs (microcontrollers) and dsPIC® digital signal controllers.

ICD 4 also introduces a wider target voltage range and an optional 1 A of power via an external power supply. For maximum flexibility, MPLAB® ICD 4 features a selectable pull-up/pull-down option to the target interface and programmable adjustment of debugging speed for greater productivity.

Key Features:

- ▶ Supports many PIC® MCUs and dsPIC® DSCs
- ▶ x2 faster than MPLAB® ICD 3
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- ▶ Simplifies migration between PIC® MCUs
- ▶ High-performance 32-bit MCU core
- ▶ Increased RAM provides 2 MB of buffer memory
- ▶ Wider target supply voltage: 1.20 to 5.5 V
- ▶ Optional external power supply for 1A of power
- ▶ Programmable adjustment of debugging speed

Order Your MPLAB® ICD 4 In-circuit Debugger Today!



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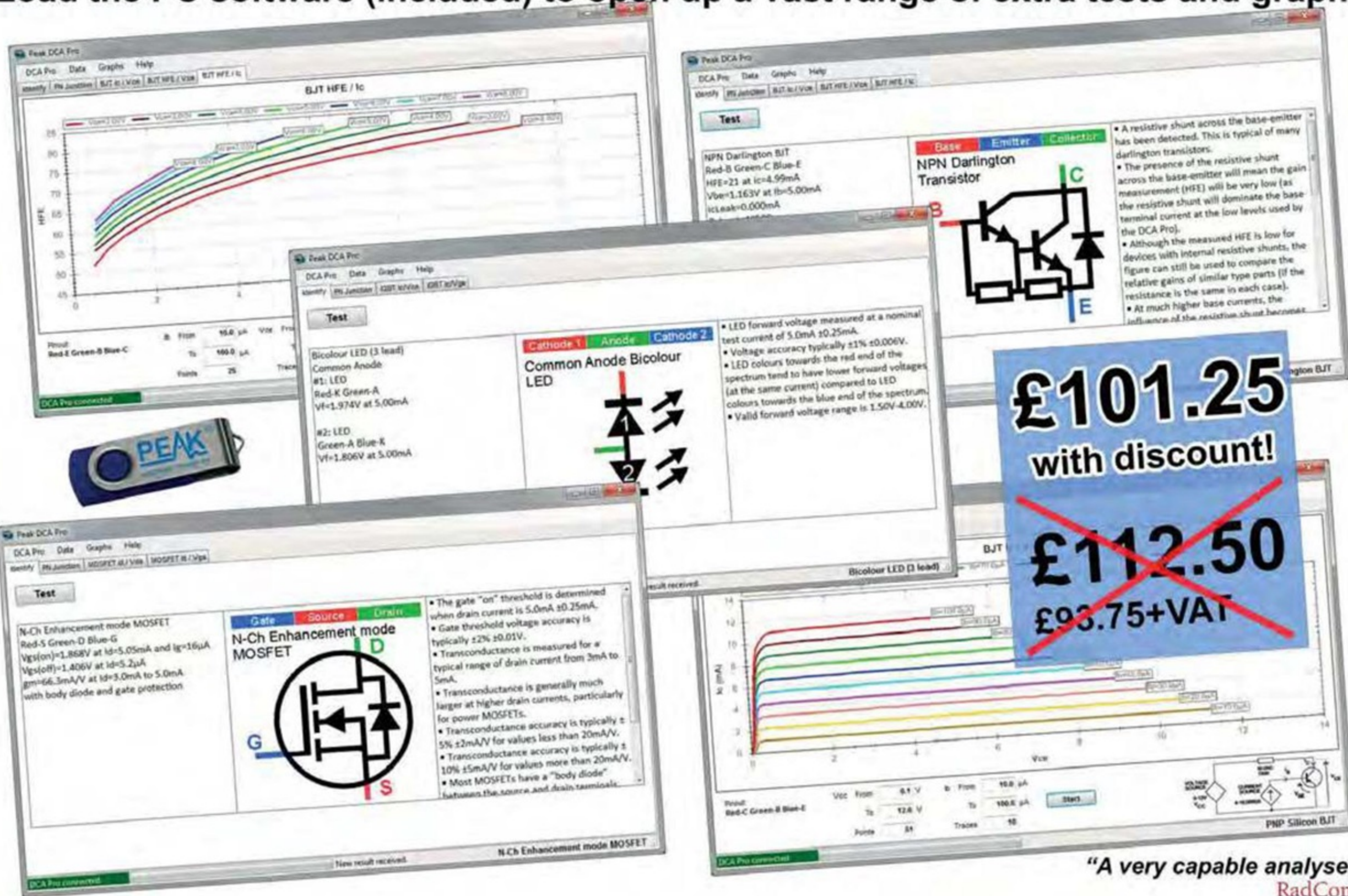
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